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A spatial analysis of public transport accessibility in Slovenia

This article analyses the accessibility of public transport in Slovenia in terms of the proximity of stops and trip frequency. By combining the Central Population Register with data on the provision of public transport services, geographic information systems were used to calculate the share of the population living within a 500 and 1,000 m radius from stops with a basic number of daily trips. The spatial differences in accessibility were analysed, and the population density data were utilized to identify the main gaps in provision. Moreover, the location of newer settlements was analysed in terms of their integration into the existing public transport network. It was determined that public transport accessibility in the country is relatively adequate within a 1,000 m radius; however, within a 500 m radius, it is adequate only in most urban areas. There are extensive areas without adequate accessibility, which is a consequence of low population density particularly in the countryside, whereas larger gaps in provision appear in suburban areas that have grown outside public transport corridors. The 2004–2020 study period revealed a trend of lower demographic growth than the Slovenian average in areas with the best public transport accessibility, whereas the areas of the greatest population growth and most intense residential construction have been only partly located in the vicinity of the public transport network. This confirms the hypothesis that current strategic spatial planning documents are not followed consistently, and that transport and spatial planning are insufficiently integrated.

Keywords: accessibility, mobility, public transport, settlement, spatial planning

1 Introduction

Public transport is an important element of the transport system, allowing mobility without the use of one's own vehicle, especially where distances are too great for active mobility. Since the nineteenth century, public transport has boosted city growth by increasing the capacity of transport systems and the ensuing intensity of the circulation of people, goods, and capital (Uršič, 2006) while preventing the social exclusion of people living in the countryside during accelerated modernization (Gabrovec et al., 2021). With the upsurge of private transport in the developed world (including Slovenia) in the second half of the twentieth century, public transport gradually began falling out of favour. Nowadays, a suitable quality and accessibility of public transport are major goals of sustainable transport, environmental, and spatial policies. This is because public transport offers numerous social, economic, and environmental benefits, such as reducing social exclusion, increasing employment rates, and reducing greenhouse gas emissions (e.g., Nazari Adli & Donovan, 2018; Saif et al., 2018).

Public transport accessibility is a very broad term with no clear consensus on its definition (Lei & Church, 2010). It is often regarded as one of the fundamental dimensions for measuring the quality of public transport; for example, in accessibility standards (Gabrovec et al., 2009). Several accessibility models have been developed that are used to analyse the situation for planning purposes or to verify the efficiency of measures. One of the most commonly analysed accessibility elements is the proximity to public transport stops from various starting points (Saghapour et al., 2016), and the more seldom analysed – but no less important – aspects are the time and cost of the journey, the number of possible destinations, users' needs, and similar (for an overview, see Lei & Church, 2010; Mavoa et al., 2012; Saghapour et al., 2016; Malekzadeh & Chung, 2020). Regardless of the different approaches, there is a general consensus that such measurements are useful or even crucial (Mavoa et al., 2012) because good public transport accessibility positively affects its use (e.g., Chowdhury et al., 2016; Curtis et al., 2019). The choice of transport mode is also predicated on many other factors, such as individual (psychological and situational), spatial (population and activity/service density), infrastructural (network of roads, routes, or stops), temporal (travel speed and duration), and political factors (transport policies; e.g., Collins & Chambers, 2005; Buehler, 2011). Similar criteria can be applied to public transport (Beirão & Sarsfield Cabral, 2007).

Malekzadeh and Chung (2020) carried out an extensive overview of the approaches to evaluating the accessibility of public transport and categorized them into three groups:

1. System accessibility models. These are mostly limited to measuring the accessibility of public transport stops, mostly within a walkable distance. This approach has significant drawbacks because it focuses on measuring the availability of the system and not necessarily accessibility for using it; however, it is relatively easy to use and therefore quite popular. In addition to opportunities, more complex models of this kind also consider travel demand (e.g., the spatial distribution of the population and employment), whereas on the demand side waiting time and frequency, often of various types of transit (Wu & Hine, 2003), are considered in addition to the distance to the stops. Instead of a specific radius, more advanced, gravity-based system accessibility approaches consider the distance decay function (Gutiérrez et al., 2011) because the attractiveness of individual locations does not diminish linearly with increasing distance (Taylor, 1975). The authors also place utility-based models in this group, based on the benefits that different user groups have with the proximity of individual stops (e.g., Rastogi & Krishna Rao, 2003).
2. System-facilitated accessibility models consider both the accessibility of the transport system and passengers' options for reaching the desired destination by taking into account the travel time or cost of the selected route. The most advanced models of this kind utilize the cumulative approach; for example, by determining the number of residents with access to a certain location within a specified time or cost (Liu & Zhu, 2004). Their drawback is that they do not consider the significance of the options from the viewpoint of the individual resident or passenger.
3. Integral accessibility or access-to-destination models measure the overall access to a number of possible destinations, indicating how easy it is for people to travel with public transport. The development of geographic information systems has led to the development of numerous models; that is, tools whose features allow their further categorization into distance-based, gravity-based, and utility-based access-to-destination models. This approach best highlights travellers' difficulties accessing various destinations (Fransen et al., 2015), but it is the most complex to utilize and interpret; in addition, the aggregated results reduce model accuracy.

By far the most extensively used studies in Slovenia fall into the first group; that is, system accessibility models. One such example is the PTAL (Public Transport Accessibility Level) index calculation for Ljubljana, which considered the proximity of bus stops, the average waiting time, and trip frequency (Tiran et al., 2014, 2015). This group also includes studies on the accessibility of bus stops in Slovenia (Gabrovec & Bole, 2006), public transport accessibility in the Ljubljana Urban Region (Gabrovec & Razpotnik Visković, 2012, 2018), an analysis of the accessibility of public services with interurban passenger transport (Zavodnik Lamovšek et al., 2010), a comparison of the accessibility of city bus stops in Ljubljana using various methods (Kozina, 2010), and a multistage model to calculate uniform bus stop service areas (Paliska et al., 2006). The public transport accessibility index has also been used for evaluating regional development (Pečar, 2020). Another study by Tiran et al. (2019) modelled walking accessibility to urban amenities in Ljubljana based on the concept of distance decay, whereby it surveyed the residents of Ljubljana on their perception of what a suitable walking distance is, including to public transport stops. Studies based on the other two approaches are rarer. They study accessibility to selected locations with public transit, and so they can be included in the system-facilitated models (Koblar et al., 2019; Koblar & Mladenovič, 2020; Koblar, 2021a, 2021b; Tiran et al., 2021).

The first comprehensive public transport accessibility study for Slovenia was performed by Gabrovec and Bole (2006), who considered both proximity to bus stops and trip frequency. They analysed interurban passenger transport and calculated the accessibility on different reference dates for a 500 and 1,000 m radius. They determined that the network of bus lines is adequately dispersed across Slovenia; over three-quarters of the population have adequate bus connections within a 1,000 m radius on weekdays during the school year, whereas the provision is significantly reduced or even unsatisfactory on other days. A different study performed in about the same timeframe determined that interurban passenger transport offers relatively satisfactory accessibility to public services, but that it is outperformed by car travel (Zavodnik Lamovšek et al., 2010). Another relevant study analysed the adequacy of the public transport network in the Ljubljana Urban Region in terms of dispersion of settlement and detected some gaps in the provision of public transport services (Gabrovec & Razpotnik Visković, 2012).

The settlement pattern relative to the public transport network in Slovenia is regulated in detail by the General Settlement Guidelines (Splošne smernice, 2013). These guidelines stipulate that planning and managing a wider urban area should consider the possibility of connecting to public transport, and that residential construction should be directed into denser areas where efficient and comfortable public transport can be provided. The guidelines for economical land use in urban areas place the most attention on areas with good accessibility and well-organized public transport. The guidelines summarize the current Spatial Development Strategy of Slovenia (Strategija prostorskega, 2004), which emphasizes well-connected and synchronized development of the transport and settlement networks along with building public infrastructure as one of the priorities. Public transport accessibility is also addressed in the General Guidelines for Sustainable Mobility (Demšar Mitrovič, 2018), which stress that, in practice, large new residential construction projects do not have an alternative to cars, which can be overcome with accessibility standards. No document defines what a suitable distance from residential areas to public transport stops is. The Spatial Development Report (Fonda et al., 2016) and the latest draft of the Spatial Development Strategy (Strategija prostorskega, 2020) emphasize that the settlement pattern and the public transport network have not developed in synchronicity. This has also been concluded by some studies pointing to the spatial dispersion of activities in Slovenian cities and suburbs, increasing commuting and traffic flows, and the increasingly dispersed travel patterns that worsen the competitiveness of public transport (Rebernik, 2010). As was found to be the case in Ljubljana, modern high-rise housing developments are no longer tethered to public transport to the extent that they were in the past (Bole, 2004). Public transport accessibility across the country, especially in terms of settlement trends, has not been thoroughly analysed yet. It is reasonable to assume based on these reports and studies that current spatial planning documents are not followed consistently, and the integration of traffic and spatial planning is low.

This article analyses public transport accessibility in Slovenia in terms of proximity to stops and trip frequency. The analysis focuses on the accessibility of public transport stops to people's dwellings because these are the most important origin of travel. The following objectives were set:

- To analyse public transport accessibility across the country;
- To determine the adequacy of the public transport network in terms of the settlement pattern and identify the main gaps in the provision of public transport services; and
- To analyse contemporary settlement changes in the vicinity of public transport stops.

2 Methodology

The analysis was carried out using geographical information system tools utilizing population data at the level of individual house numbers and travel timetables of all kinds of available public transport in Slovenia.

2.1 Input data preparation

The population data for 2004 and 2020 were gathered at the house-number level (Centralni register, 2005/2021); to calculate the number of residents at an individual house number, the statistical definition of a usual residence at the time was followed. In the accessibility calculation for 2020, the case of a person having both a permanent and temporary residence was resolved by using the temporary residence (section 3.1), and the temporary comparability in the settlement change analysis (section 3.2) led us to use only the permanent residence, not the temporary one. The Central Population Register was linked to the House Number Record for each of the years, which contains the geographic coordinates of buildings with house numbers (Geodetska uprava, 2005/2021).

The analysis focused on the days with the greatest traffic demand, and so the public timetable data with the locations of the public transport stops correspond to a typical workday during the school year in 2021. These were acquired from multiple sources: the first data source was the Ministry of Infrastructure, which uses the IJPP application to manage data on interurban passenger transport and rail timetables (IJPP aplikacija, 2022). The database also contains data on some city itineraries, but these data are not regularly updated, and so the only data on city travel itineraries used from this source were for public transport in Novo Mesto and Murska Sobota; the timetables for the public transport in other cities were obtained directly from the service providers. Some of the service providers did not enclose coordinates of the stops; in these cases, the coordinates were determined with field visits. Some municipalities, particularly those in Alpine areas, also offer public transport for tourists in the summer and/or winter season, but this does not operate on the typical workday set for our analysis. The analysis of settlement changes in terms of the public transport network between 2004 and 2020 considered stops with suitable or adequate accessibility (see section 2.2), and public transit data for 2021 were used to pinpoint the stops.

2.2 Determining the distance to stops and trip frequency

Studies on the accessibility of public transport usually use a distance that is still acceptable for daily walking to stops: the most commonly used and generally accepted distances are 400 m for bus stops and 800 m for rail transit, which correspond to five and ten minutes of walking, respectively (Saghapour et al., 2016). Travel habit studies indicate varying deviations from these distances: in some places (e.g., outside urban areas), these routes can also be longer (El-Geneidy et al., 2010). This led our analysis to set 500 m and 1,000 m distances: the former was mostly used to evaluate accessibility in urban areas and the latter in the countryside; the same radii were also used to determine gaps in the provision relative to the population density (see section 2.3).

When evaluating trip frequency, we modelled our study on that by Gabrovec and Bole (2006), distinguishing between unsuitable, adequate, and suitable frequency. Stops with an adequate frequency have at least eight pairs of trips a day. This means a potential traveller has at least two to three trips in each direction during both the morning and afternoon peak times, as well as at least one trip outside peak times in the morning, afternoon, and evening. This kind of provision allows travellers to commute for work and school and partly for other purposes, but it cannot compete with personal transport. A suitable provision was determined to be one availability for at least twenty-three pairs of daily trips, constituting a half-hour interval during peak times and one-hour intervals outside them. This analysis summed up departures from all the stops of individual stations. If a station consisted of several modes of transport (interurban passenger transport, train, and city public transport) in the same location or the stops were less than 200 m (straight line) apart from one another, they were considered a single station and the departures of all the modes of transport from all the stops were tallied.

The distance from residences (house numbers) to the stops were calculated based on straight-line distance. We created a buffer area in a radius of 500 m around each point representing a house number; then we checked whether the buffer contained a station with a certain category of trip frequency. In cases where there were several such stations, we considered the one with the best frequency. The data on the station with the trip frequency were ascribed to an individual house number. The process was then repeated for the buffer area in a radius of 1,000 m.

2.3 Identifying gaps in provision

By cross-referencing the data on public transport stops and the calculated population density, we were able to pinpoint gaps in the provision. First, we determined densely and very densely populated areas. Densely populated areas were defined as house numbers with over 200 residents within a 500 m radius, and very densely populated areas were defined as those with over 1,000 people living within a 500 m radius around the house number. In densely populated areas, gaps in the public transport provision were defined as places where buildings are over 1,000 m from a public transport stop; in very densely populated areas, these are buildings that are over 500 m away (Gabrovec & Razpotnik Visković, 2012). The gaps were calculated in terms of the proximity to the nearest stop as well as to stops with an adequate trip frequency (at least eight pairs of trips a day). These data on density are directly transferrable to public transport planning: according to German recommendations, quality public transport should connect all areas where at least 200 people live in an influence area (Heußner et al., 2001, p. 12).

3 Results

3.1 Public transport accessibility in Slovenia

The results of the calculation for a 1,000 m proximity to public transport spots are reasonably encouraging. Only about a tenth of the population lives outside these areas, whereas over three-fifths have a stop with suitable accessibility within that distance. As expected, the results of the calculation for a 500 m proximity are somewhat poorer: the greatest differences occur in the share of residents that do not have a public transport stop within that distance – it jumps from about a tenth (8.3%) to just under a fourth (23.2%) – and in the share of residents with suitable accessibility, which falls from about two-thirds (61.8%) to under half (49.4%; Figure 1).

3.1.1 Spatial differences in accessibility

There are considerable differences in public transport accessibility within the country, especially in terms of the smaller, 500 m radius (Figure 2). Some municipalities have very good accessibility according to both the stop proximity criterion and the trip frequency criterion: these are mainly more densely populated municipalities with larger urban centres and some municipalities in their surrounding countryside, of which some also have their own city bus transport. The two largest city municipalities, Ljubljana and Maribor, along with Jesenice, lead here: over 90% of the population resides within a 500 m radius of a stop with suitable accessibility. Somewhat lesser, but still very good, accessibility was found in the municipalities of Kranj, Velenje, Škofja Loka, Murska Sobota, Trbovlje, and Izola, as well as the smaller municipalities of Ruše, Mežica, Mengeš, Miklavž na Dravskem Polju, Naklo, and Šempeter–Vrtojba. Of the city municipalities, Krško and Ptuj stand out negatively due to the dispersed settlement pattern outside the city centres: only 27 and 36% of the residents live in areas with a suitable trip frequency within a 500 m radius, and the municipality of Slovenj Gradec, where a high (44%) share of residents that do not have a public transport stop in that proximity at all, is especially problematic.

The differences across the country are somewhat smaller considering the criterion of the 1,000 m distance, which is more suitable for municipalities with a smaller urban population. Among those municipalities, there are differences between those in which the vast majority of the population has a public transport stop with an adequate trip frequency (between eight and twenty-two pairs of trips per day) – including municipalities such as Ankaran, Odranci, Destrnik, Preddvor, Dobrovnik, and Središče ob Dravi – and between municipalities where the vast majority of the people have a guaranteed connection at that distance, but the trip frequency is inadequate (fewer than eight pairs of trips per day): many of these are located on the outskirts of the country; for example, in Prekmurje (Kobilje, Razkrižje, Šalovci, and Gornji Petrovci) and in the municipalities of Brda and Kostel. Another type of municipality has centrally located municipal centres within the main public transport corridors with a relatively large share of people with suitable accessibility (over two-thirds) on the one hand, whereas the scattered settlement in the countryside surrounding these centres mean that a large share of residents (over a third) live outside an adequate distance to stops on the other hand. This group includes most of the municipalities in

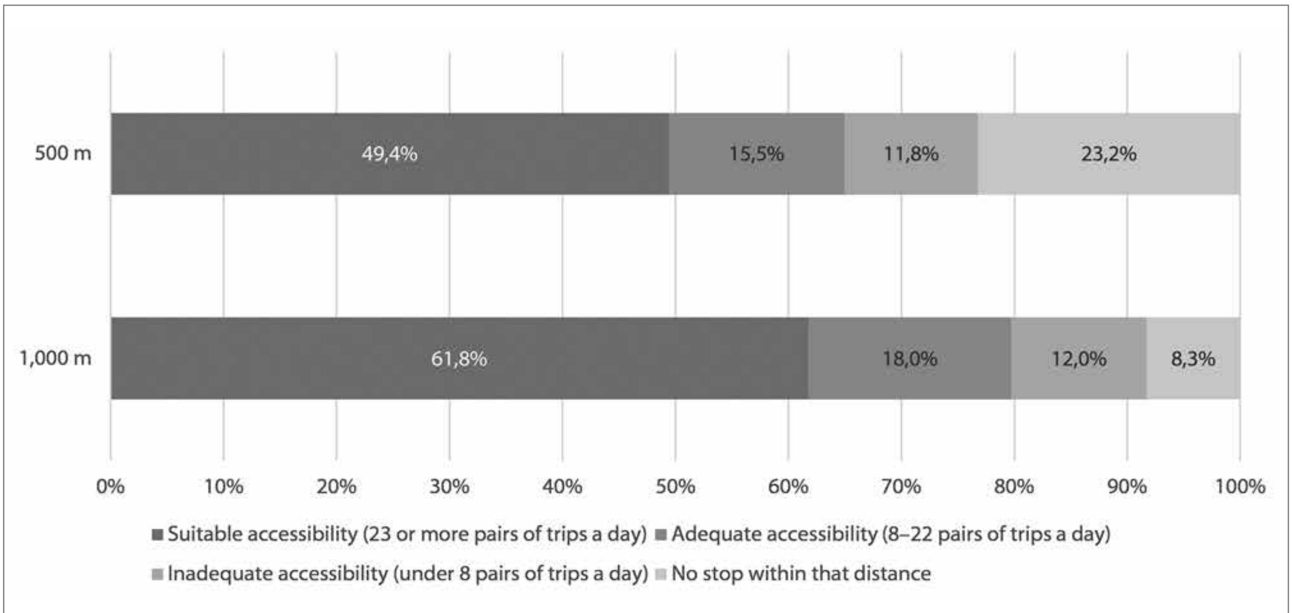

Figure 1: Public transport accessibility in Slovenia in 2020 within a 500 and 1,000 m radius in terms of trip frequency (illustration: Jernej Tiran).

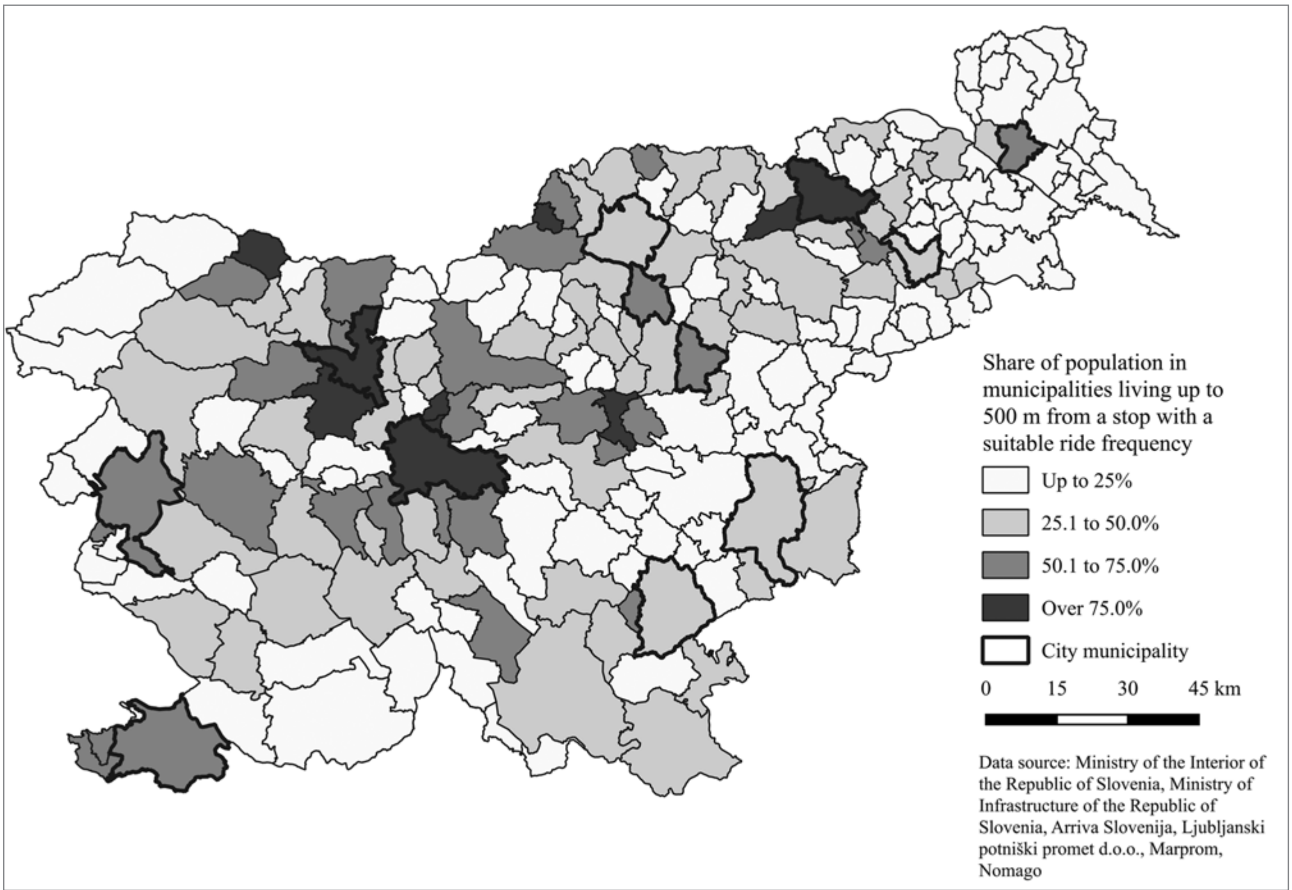

Figure 2: Share of residents per municipality living within a 500 m radius from a public transport stop with a suitable trip frequency (at least twenty-three trips a day) (illustration: Nika Razpotnik Visković).

Carinthia, as well as some municipalities in the Upper Savinja Valley (Mozirje and Rečica ob Savinji), and Ribnica.

There are also a reasonably large number of municipalities in which the major share of the population lives within a distance to public transport stops that is outside the still walkable 1,000 m radius (Figure 3). These include, for example, more remote municipalities south of Ljubljana, those in the Škofja Loka Hills, municipalities in a large share of Lower Carniola, the Sava Hills, the Kozje and Haloze regions, and the majority of Carinthia, where the share is somewhere between 30 and 47%. Considering the trip frequency criterion, the municipalities of Sodražica, Osilnica, and Bloke stand out expressly negatively, where not a single resident has available public transport frequency that would be at least adequate.

3.1.2 Gaps in provision

The absence of adequate proximity to a public transport stop is especially characteristic of sparsely populated areas, where setting up effective public transport is very challenging. To a lesser degree, the same is true for more densely populated areas where better public transport provision could reasonably be expected. In Slovenia, 33,556 people live in very densely populated areas that are over 500 m from the nearest public transport stop; this corresponds to 6.7% of the population that does not have a stop within 500 m. A number of such areas lie north of Ljubljana in the municipalities of Domžale, Mengeš, Komenda, and Trzin; these are mostly confined areas of newer, single-family houses that were built outside public transport corridors (Figure 4). If the calculation considers stops with at least adequate accessibility (eight or more pairs of trips a day), the number of residents in very densely populated areas without suitable accessibility jumps to 51,256 people. Some gaps in the provision were also located in city municipalities.

Altogether, 20,859 people live in densely populated areas that are over 1,000 m from the nearest public transport stop; this corresponds to 11.8% of the population that does not have a stop within 1 km. Many such areas encompass dense villages; for example, Bevke in the Ljubljana Marsh, Dolenja Vas and Dolenje Jezero near Cerknica, the string of settlements east of Ajdovščina running along the foot of the Trnovo Forest Hills (Gojače, Kamnje, Skrilje, and Lokavec), or periurbanized areas in the Ljubljana Urban Region (Golo Brdo and Kamnica).

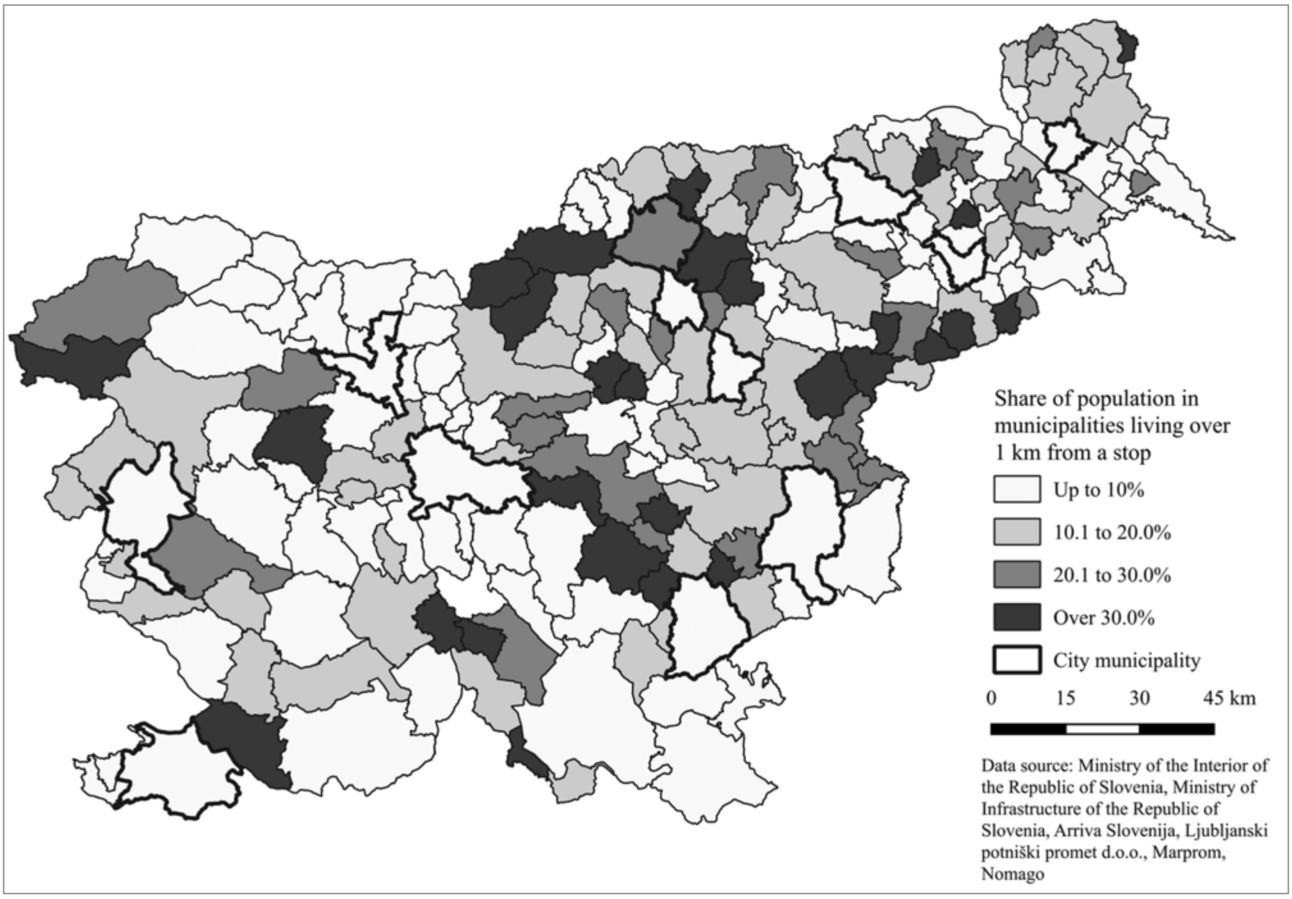

Figure 3: Share of population in municipalities living over 1 km from the nearest public transport stop (illustration: Nika Razpotnik Visković).

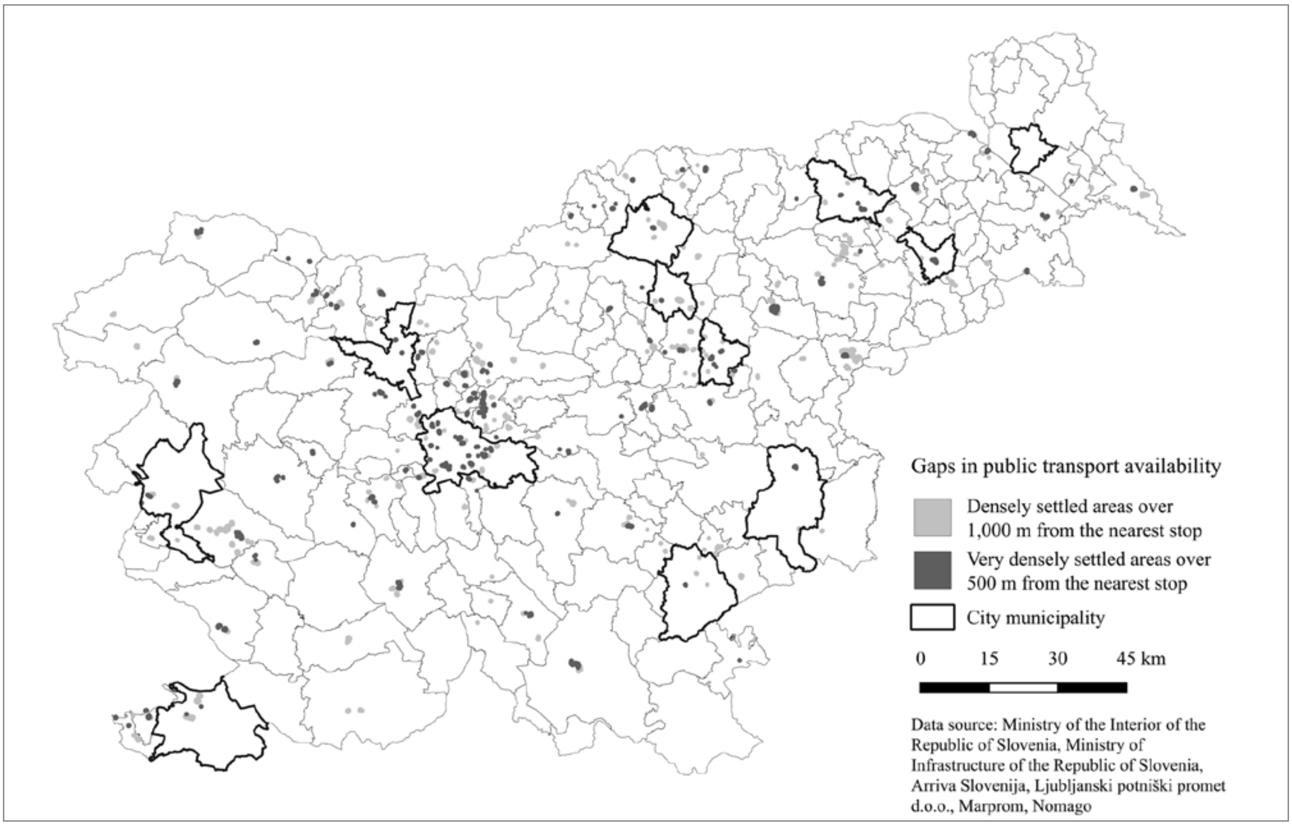

Figure 4: Gaps in public transport provision in Slovenia relative to population density (illustration: Nika Razpotnik Visković).

Table 1: Population changes in selected municipalities, 2004–2020.

Municipality	Absolute population growth	Absolute population growth in vicinity of stops (≥ 500 m)
Pivka	235	247
Benedikt	396	407
Trzin	168	231
Vransko	84	91
Cirkulane	6	15

Source: Central Population Register, 2005/2021.

Considering only stops with at least adequate accessibility, the number of residents rises drastically to 92,168. In some municipalities located outside the main public transport corridors, the share of these residents exceeds 50% (Bovec, Velika Polana, and Loški Potok) or even 80% of the total population in the municipality (e.g., Kobilje).

3.2 Analysis of settlement changes in the vicinity of public transport stops

Public transport accessibility is affected not only by the stop distribution and suitable trip frequency, but also by directing settlement into the vicinity of existing public transport infrastructure. Between 2004 and 2020, the population of Slovenia rose by 43,304 or 2.2%, whereby one hundred Slovenian municipalities recorded an increase in population, and 112 municipalities recorded a decrease (most of these are border and mountain municipalities).

The results indicate that, on average, settlement between 2004 and 2020 did not follow public transport infrastructure. In the period studied, the absolute number of people living within 500 m of a public transport stop with suitable or adequate accessibility (i.e., stops) rose by 0.4% (a difference of 5,183 people), whereas the relative share of the population in these areas dropped by 1.1% (from 64.8 to 63.7%). If the distance to the stop is increased to 1 km, 1.9% more people lived in those areas in 2020 than in 2004 (a difference of 29,351 people), whereas the relative population share dropped by 0.2%, from 79.0 to 78.8%. It is also noted that the share of people living further than 500 m from a public transport stop grew by 6.3% in that period (29,064 people) and by 4.7% for people living further than 1,000 m away (8,020 people). Settling in the vicinity of public transport stops therefore decreased at the national level during the period studied, with noticeable local differences that are explained in greater detail below.

The comparison of the share of the total population living within 500 m of stops for 2004 and 2020 indicates that it decreased in 141 municipalities (including all city municipalities) and increased in fifty-eight municipalities, whereas no change was recorded in thirteen municipalities; however, these are municipalities with no settlements near stops at all. The municipalities of Benedikt (11%) and Dol pri Ljubljani (5.8%) recorded gained shares of over 5% (Figure 5).

The comparison for the distance of 1 km indicates that the share of people living in this zone increased in ninety-one municipalities, decreased in 105 municipalities (including all city municipalities), and remained unchanged in sixteen municipalities. The largest share was again seen in the Municipality of Benedikt (7.7%), followed by Hodoš (6.6%), and Divača (5.1%; Figure 6).

3.2.1 Trends in municipalities with positive demographic growth

The first municipalities listed are those that directed population growth to areas near public transport stops. Considering the 500 m distance, there are five such municipalities: Trzin, Vransko, Pivka, Benedikt, and Cirkulane. The number of residents in areas near stops in all five municipalities increased by at least as much as the growth in the total absolute number of residents (Table 1). All five municipalities recorded above-average population growth compared to the national average, with the Municipality of Benedikt standing out significantly: it recorded 18% demographic growth between 2004 and 2020. If the distance to the stop is increased to 1 km, the number of municipalities recording the trend nearly triples (Figure 7). These cases involve either population growth in established settlement areas or new residential construction being appropriately located in the vicinity of stops, or a combination of both.

Of the ten municipalities with the greatest level of population growth, the first nine are in the Central Slovenia Region. In some, most of the population growth is in areas within 500 m of a public transport stop, whereas in others (Logatec, Ivančna Gorica, and Rače–Fram) that share is very modest and indicates that the focus of the settlement is shifting from the stops outward. At distances up to 1 km from the stop, the trend of orienting excess population is somewhat more favourable. In six municipalities, over 90% of the population growth is in areas under 1 km from public transport stops (Table 2).

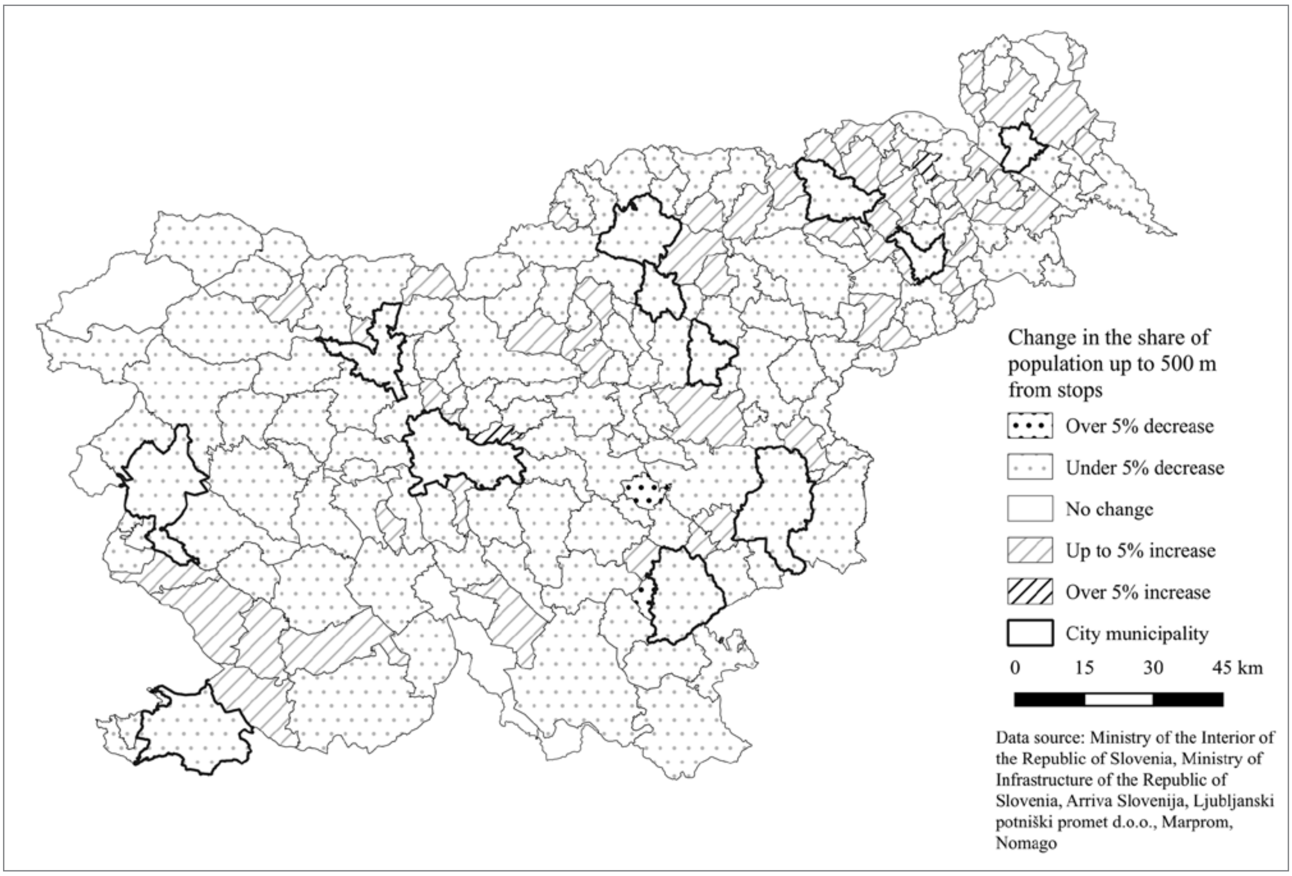

Figure 5: Changes in the share of population living near public transport stops, 2004–2020 (up to 500 m) (illustration: Nika Razpotnik Visković).

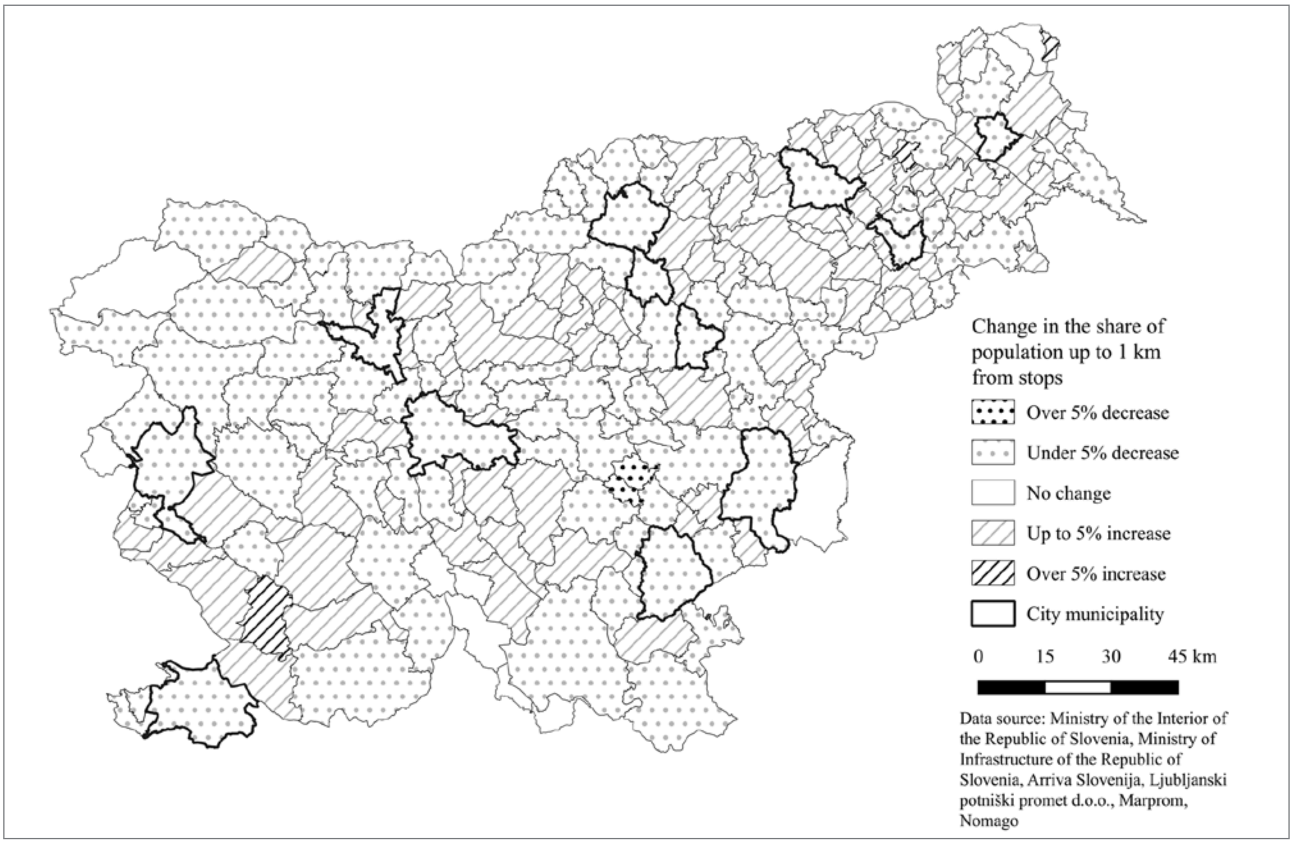

Figure 6: Changes in the share of population living near public transport stops, 2004–2020 (up to 1 km) (illustration: Nika Razpotnik Visković).

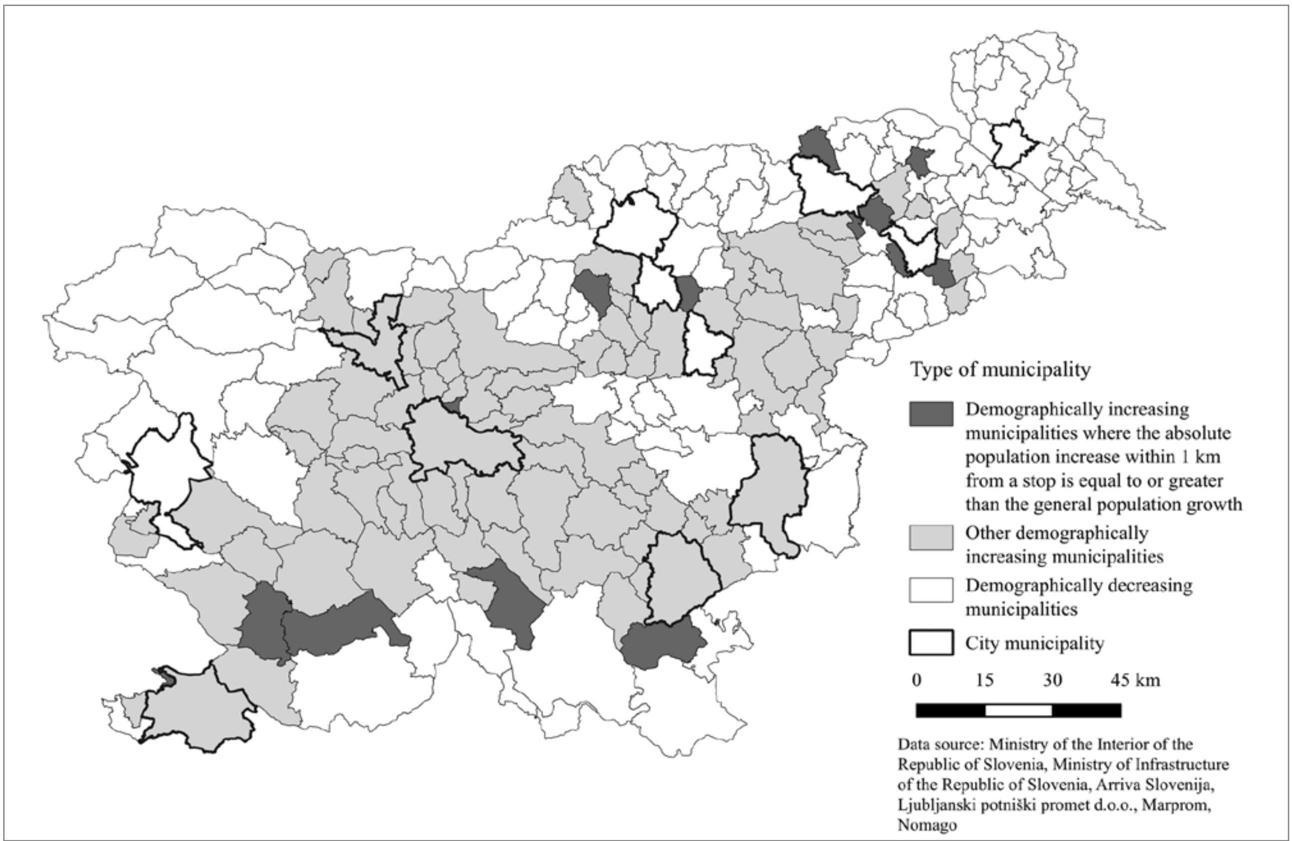

Figure 7: Municipalities with favourable settlement placement in terms of vicinity of public transport stops, 2004–2020 (distance up to 1 km) (illustration: Nika Razpotnik Visković).

Table 2: Directing population growth between 2004 and 2020 in municipalities with the greatest population growth.

Municipality	Relative population growth (%)	Absolute population growth (no. of people)	Share of people in population growth ≤ 500 m from stop (%)	Share of people in population growth ≤ 1 km from stop (%)
Škofljica	47.2	3,572	79.6	93.7
Komenda	38.3	1,766	52.8	96.5
Dol pri Ljubljani	36.2	1,663	85.4	92.7
Ig	27.9	1,590	77.2	91.1
Brezovica	27.9	2,727	76.9	91.5
Vodice	23.4	958	81.1	93.3
Grosuplje	23.2	3,834	68.1	88.9
Logatec	21.2	2,486	43.2	83.2
Ivančna Gorica	20.5	2,880	41.8	70.3
Rače–Fram	19.9	1,277	13.6	55.9

Source: Central Population Register, 2005/2021.

3.2.2 Areas of demographic decline

When analysing municipalities facing depopulation, we verified whether this is concentrated in areas with a greater distance from public transportation stops. The analysis results do not confirm this. In these municipalities, the absolute number of people living in areas where the distance to the nearest stop exceeds 500 m has decreased by 3,830 people or 1.8% since 2004; these are predominantly rural and border municipalities that already have poorer public transport accessibility: Ormož, Radenci, Laško, Pesnica, and Rogaševci. The number of inhabitants in areas within a 500 m radius to stops decreased by 37,485 during the period studied, which is a 6.9% decrease (the highest in urban areas, such as Maribor, Trbovlje, Velenje, Jesenice, Celje, Ptuj, Murska Sobota, and Hrastnik). The situation is similar at the 1 km scale. The number of people that are over 1 km from stops decreased by 2,312, which is a 3.1% decrease compared to 2004, and by 38,057 in areas with a distance up to 1 km, which is a 5.7% decrease. The geographical pattern is similar to that at the 500 m distance.

Table 3: Slovenian municipalities with the most intense residential construction.

Municipality	Pop. in 2020	Pop. growth 2004–2020 (%)	Constr. permits 2007–2020 / 1,000 res.	Population share change			
				≤ 500 m from a stop (%)	> 500 m from stop (%)	≤ 1 km from stop (%)	> 1 km from stop (%)
Komenda	6,383	38.2	134.3	−2.3	2.3	1.2	−0.6
Benedikt	2,584	18.1	126.1	11.1	−9.9	7.7	−4.8
Vransko	2,627	3.3	105.4	2.0	−2.2	1.3	−1.2
Hrpelje - Kozina	4,572	11.8	100.5	4.9	−1.9	4.2	−2.0

Source: Statistical Office of the Republic of Slovenia, 2021.

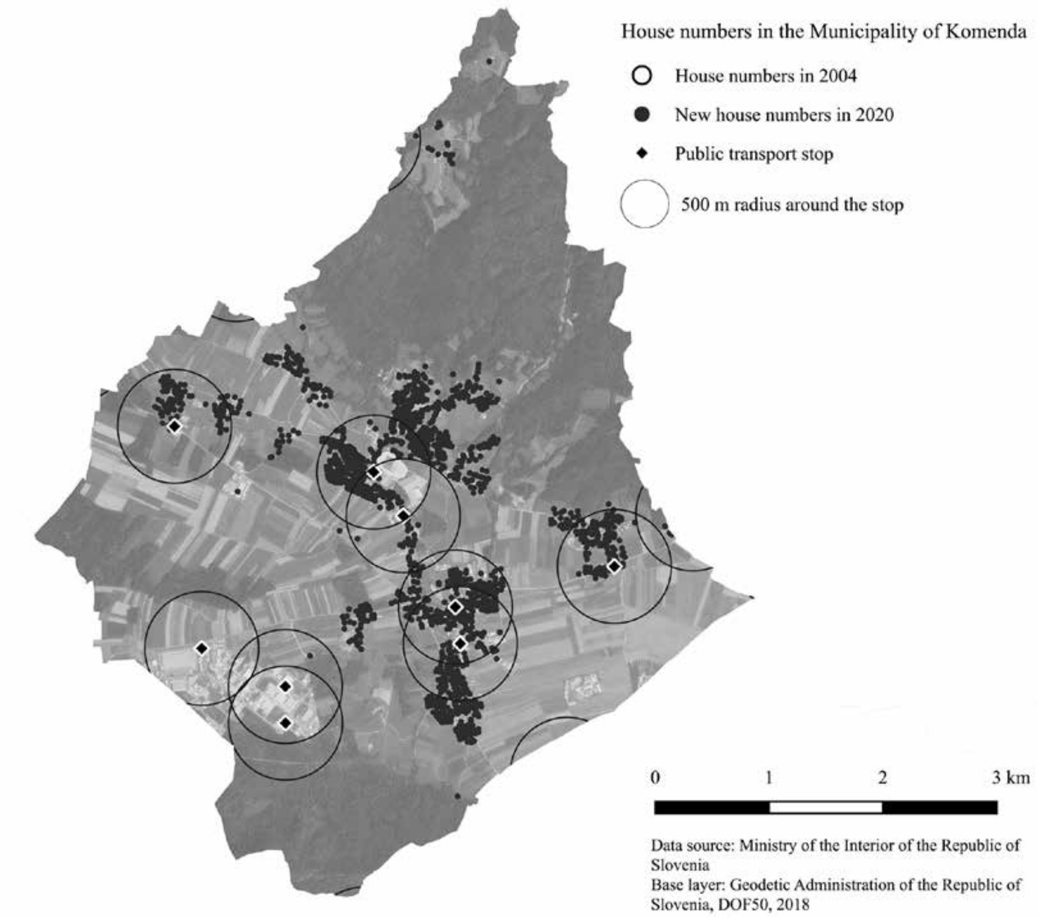

Figure 8: Locations of house numbers with permanent residence in the Municipality of Komenda (illustration: Nika Razpotnik Visković).

3.2.3 Selected areas of intense residential construction

Finally, we would like to highlight the suitability of directing settlement based on the case of Slovenian municipalities that recorded an intense settlement dynamic, which is demonstrated by the number of building permits for residential construction from 2007 to 2020 (Statistični urad, 2021). These are Komenda (Central Slovenian Region), Benedikt (Drava Region), Vransko (Savinja Region), and Hrpelje–Kozina (Coastal–Karst Region) (Table 3).

The Municipality of Komenda was not very effective in locating settlements near public transport stops from 2004 to 2020. Settlement mostly spread because single-family houses were built on the edges of settlements, but too far from public transport stops. The construction of the Šmidov Log and Sončna Aleja housing developments in Gmajnica also contributed

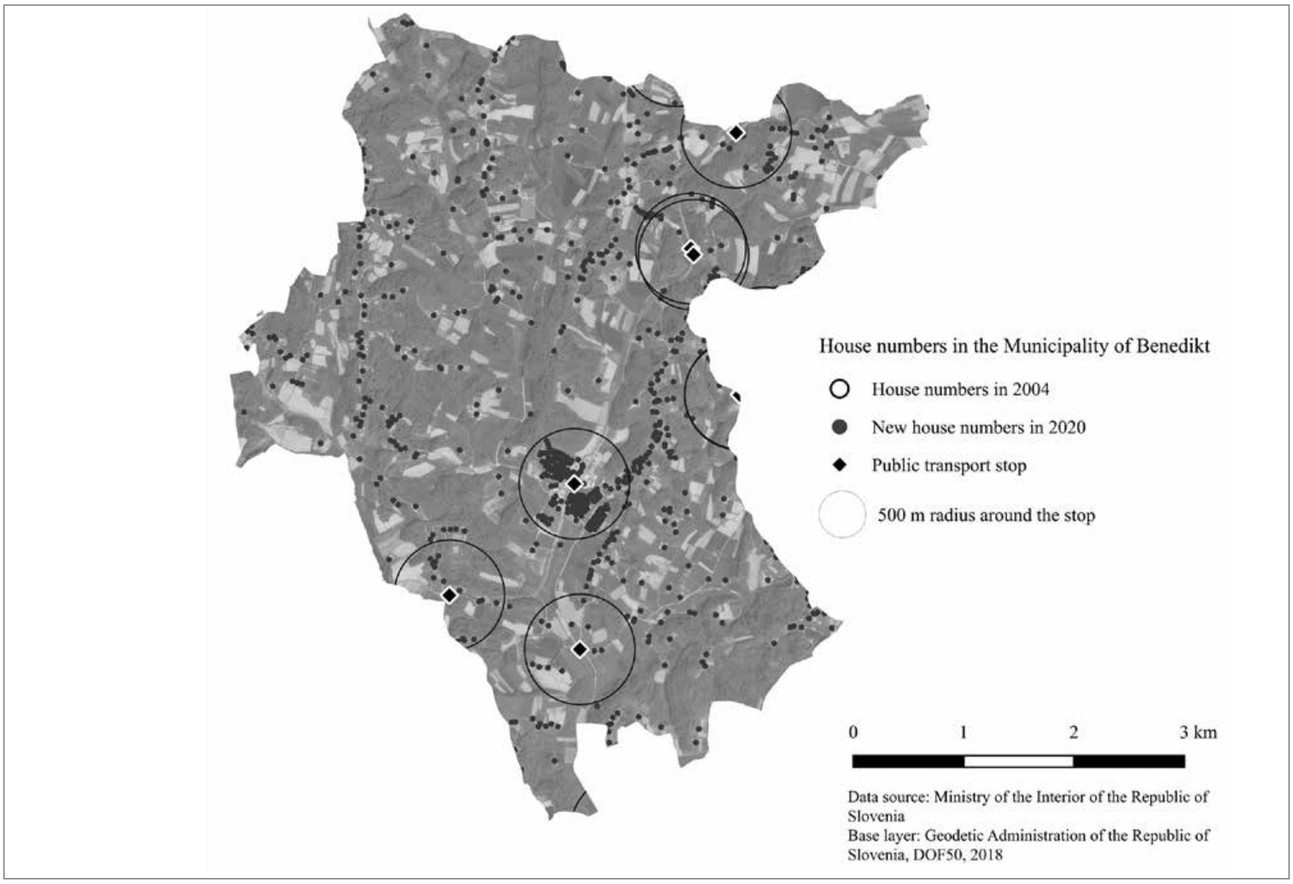

Figure 9: Locations of house numbers with permanent residence in the Municipality of Benedikt (illustration: Nika Razpotnik Visković).

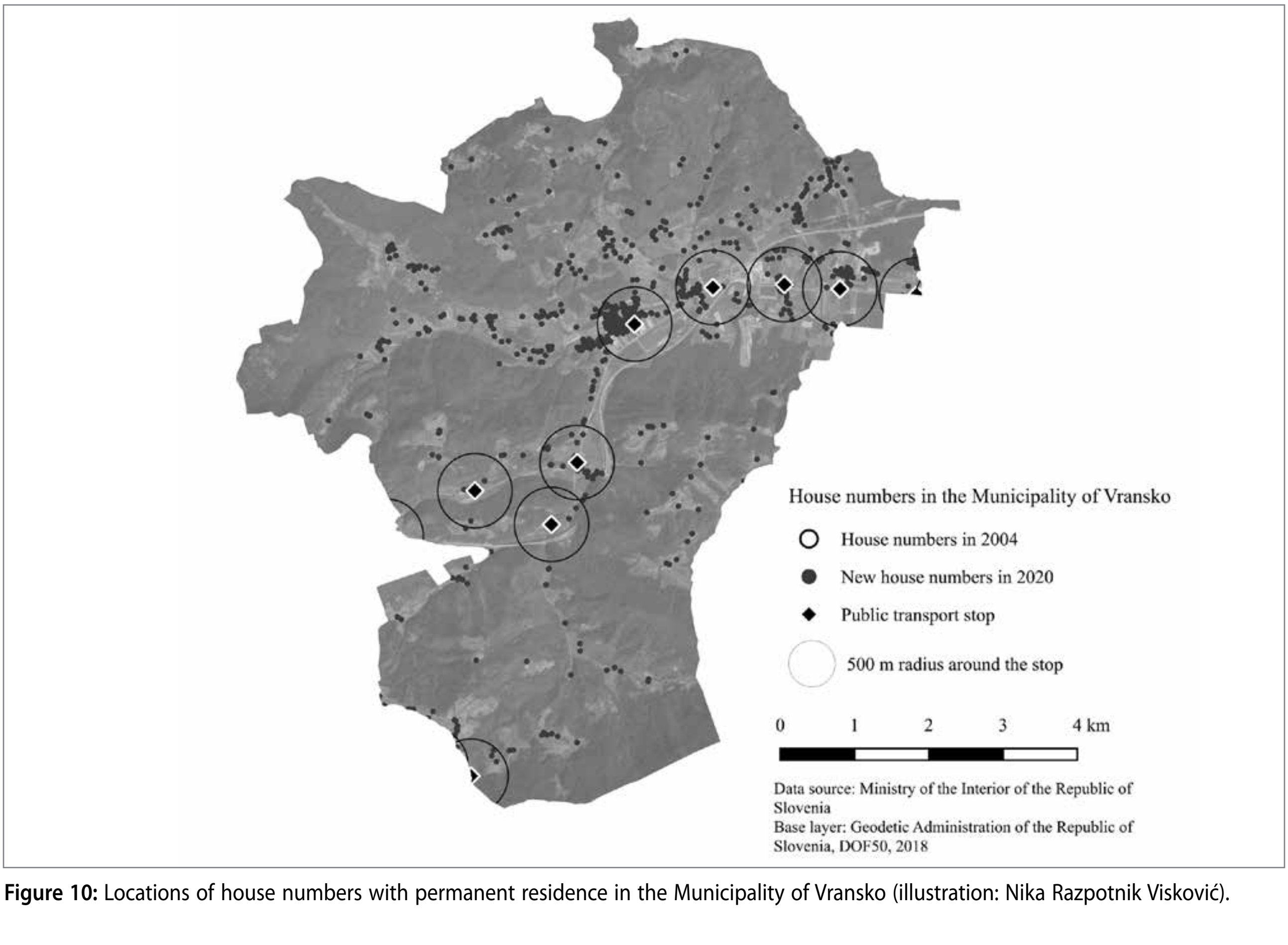

Figure 10: Locations of house numbers with permanent residence in the Municipality of Vransko (illustration: Nika Razpotnik Visković).

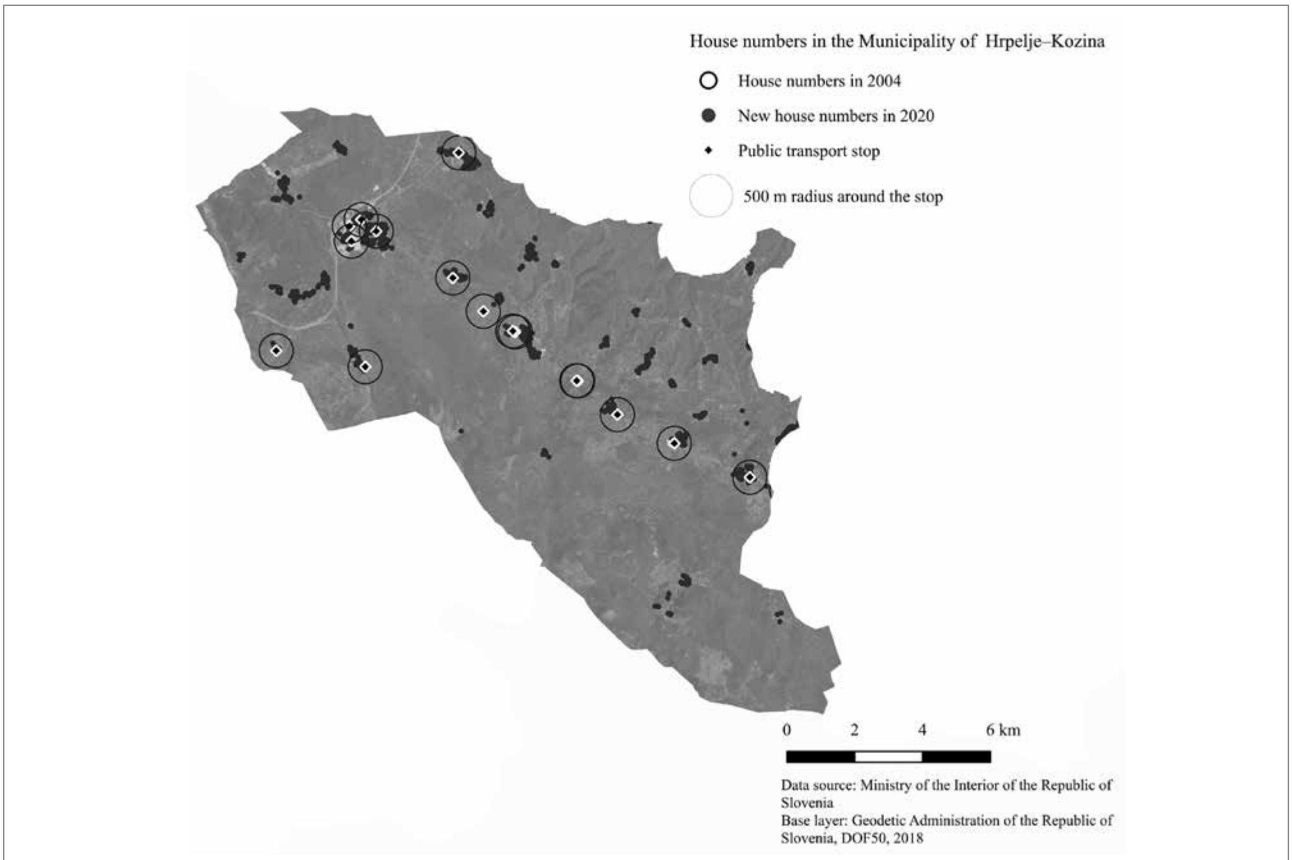

Figure 11: Locations of house numbers with permanent residence in the Municipality of Hrpelje–Kozina (illustration: Nika Razpotnik Visković).

to considerable population growth, but they are over 500 m from the nearest public transport stop (Figure 8).

The Municipality of Benedikt recorded a "progressive" residential policy in the reference period, which focused on the centre of the settlement of Benedikt v Slovenskih Goricah and in the vicinity of a stop, and is an example of paying suitable attention to public transport accessibility (Figure 9).

The Municipality of Vransko is interesting in terms of its settlement due to the vicinity of freeway access. During the period studied, growth was based on dispersed individual construction in areas that are over 500 m or 1,000 m from stops (Figure 10). In 2022, the construction of the Grofice housing development near the freeway access is also coming to an end, but it is also near a public transport stop.

The Municipality of Hrpelje–Kozina is particularly attractive for settlement due to the vicinity of freeway access, which resulted in the construction of several housing developments from 2004 to 2020 (Brinje and Sončna Pot in Kozina; a development is being built at the foot of Slavnik Hill), including scattered construction across the rest of the municipality (Figure 11). The share of residents living near public transport stops additionally increased there.

4 Discussion

The results of this public transport accessibility analysis are useful for planning achievable goals to shift travel habits, evaluating how settlement is being directed, and planning measures, such as changes to the public transport network and timetables. Some results are difficult to evaluate due to the absence of clear measures. It is difficult to determine unequivocally whether the nearly half of the population of Slovenia that does not have a public transport stop with a suitable trip frequency within 500 meters is still acceptable or not; that is, whether this significantly impedes greater public transport use. Research on the influence of the proximity of public transport stops on public transport use in Slovenia has so far only been examined for Ljubljana (Tiran et al., 2019) and Koper (Paliska et al., 2006), where willingness to walk decreases exponentially with distance (Zhao et al., 2003); the findings of similar studies from abroad are only partly applicable because of their different context. At the same time, the public transport network depends on numerous factors and limitations, such as financial means, population density, infrastructural possibilities, and actual public transport use. Regardless of this, we have determined that a significant share of the population lives in areas where public transport is not accessible enough for people to use it on a larger scale, whereby accessibility is only one of the elements of good public transport (Gabrovec et al., 2009).

The accessibility results are easier to evaluate by identifying gaps in the provision of public transport services based on population density because this is what largely determines the public transport network. These results have an important applied value because they can be used as a basis for expanding or optimizing the public transport network, and the potential measures involve changing the routes and stops and adding new ones or increasing the trip frequency on current lines. Considering the relatively low shares of the population living in (very) densely populated areas without suitable public transport accessibility, it can be concluded that the public transport network in Slovenia is relatively adequately dispersed in terms of the settlement pattern, especially for very densely populated areas in comparison to densely populated areas. However, improvements are necessary in many areas; for example, in Ajdovščina, almost the entire north-eastern part of the city lacks suitable access to public transport, despite its relatively high population density; a potential solution to this is to move a stop or introduce an additional stop nearer to the densely populated area, which would not involve great expenditure. A similar example can be identified in south-eastern Cerknica. In areas without public transportation, travel time competitiveness will have to be considered when positioning additional stops because an overly dense stop network can decrease this. In more densely populated areas where introducing new lines is not possible or sensible, new and more adaptable forms of public transport should be considered, such as demand-responsive transport, rural taxi service, or placing smaller park and rides near the nearest stop with suitable accessibility (Mees, 2009; Prinčič et al., 2016; Gabrovec et al., 2021). Adaptable forms of public transport are also necessary in more sparsely populated areas that are much more spatially extensive.

The results of the analysis of contemporary settlement changes relative to the current public transport network are not very encouraging. The population has decreased most in areas in the vicinity of public transport stops, which leads to the conclusion that public transport is not an important element when choosing a place of residence. This finding agrees with the results of some other studies (Aslam et al., 2019). In municipalities with the most intense settlement dynamics, newer settlements are partly placed in the vicinity of public transport stops; however, a detailed analysis indicates that some either do not have suitable access to public transport stops via the footpath network (e.g., Sončna Pot in Kozina), or that the vicinity of public transport stops is secondary compared to freeway access (e.g., the Grofice housing development in Vransko under construction), judging by the absence of public transport being mentioned on the development's presentation website. Current settlement can only partly follow the public transport network, which confirms the discrepancy between national strategic documents and planning practices, which has also been emphasized in the Spatial Development Report (2016) and the draft Spatial Development Strategy of Slovenia 2050 (2020). All of this is reflected in modest public transport use in Slovenia, which additionally decreased during and after the COVID-19 pandemic (Brezina et al., 2021).

Some drawbacks and limitations of the selected methodological approach should be highlighted. First, the accessibility calculation was based on the straight-line distance and not the distance on the road network. Such calculations overestimate actual accessibility, but with significant deviations between areas due to the differences in the density of the road network, natural and artificial barriers, and similar (Kozina, 2010; Tiran et al., 2015). Second, accessibility was analysed in radii of 500 and 1,000 m, which do not necessarily reflect the distance to the stop that people are willing to travel. Due to the greater availability of travel options in urban areas, 1,000 m is probably too great a distance for locals to use public transport daily unless they do not have an alternative. In light of some research that indicates people's unwillingness to walk to stops – for example, in Ljubljana (Tiran et al., 2019) – this partly also applies to the 500 m radius. The radii used do correlate with an (acceptable) walking distance, which is the most universal travel mode, but public transport stops can also be accessed in other ways. In any case, additional research is necessary to determine the desired and necessary (walking) distance to public transport stops in Slovenia, which would also serve as the foundation for establishing more precise accessibility standards.

Furthermore, the study only considered access from the travel origin (from home) to the entry stop, but not also access from the stops to potential travel destinations (e.g., workplaces), which also affects the selection of the travel mode. In terms of the public transport supply, our calculation was somewhat simplified. Even though using the data on the number of trips a day does not necessarily reflect the suitability of timetables for travellers, it is an important step forward compared to more rudimentary calculations of accessibility. In terms of public transport demand, we only considered population dispersion, but not the population's actual mobility needs or socioeconomic characteristics. This methodology also does not consider other significant accessibility elements and public transport quality, which affect the actual use of the system (e.g., travel speed and travel time). A more comprehensive overview should be developed with other travel modes (e.g., electric scooter, bicycle, and car), which would require detailed input data.

5 Conclusion

The research utilized geographical information systems to analyse public transport accessibility in Slovenia in terms of the vicinity to stops and trip frequency. We determined that public transport accessibility in the country is relatively adequate in terms of the 1,000 m radius, even if the trip frequency is considered, but less so in terms of the 500 m radius, where it is adequate only in most urban areas. Vast areas across the country, including in some city municipalities, do not have adequate public transport accessibility, which is the consequence of low population density in the countryside, and larger gaps in provision were identified in suburban areas that have formed outside public transport corridors. The analysis of the settlement changes near stops between 2004 and 2020 indicates that public transport provision is not an important locational factor. In areas of the greatest population growth and intense residential construction, settlement was only partly located in the vicinity of public transport. This confirms the assumption of inconsistent adherence to current strategic spatial planning documents, insufficiently integrated traffic and spatial planning, and continuing spatial trends that represent a shift from effective, economical, and quality spatial development.

To improve public transport accessibility in Slovenia in the future, the public transport network does not need to be significantly altered, but new settlement must be diligently located inside areas with suitable public transport accessibility, and settlements in sparsely populated areas without suitable public transport accessibility, which are extremely extensive in Slovenia, require improved provision of alternative forms of mobility.

This research has provided additional and more comprehensive insight into public transport accessibility in Slovenia, and it has introduced some new measurement tools for evaluating accessibility that are also internationally transferrable. Future research should examine the extent to which accessibility affects the frequency of public transport use in terms of both the distance from stops and trip frequency compared to other spatial characteristics (parking policy and land use) and other elements of public transport quality. For a more comprehensive image of public transport accessibility in Slovenia, the analysis should also be expanded with the socioeconomic characteristics of the population, the diversity of travel options at a given location, accessibility to the travel destination, and so on.

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