A residential location approach to traffic safety: two case studies from Germany

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abstract

This paper aims to spatially differentiate the road accident risk associated with living at a certain place of residence. Official accident data usually record the place the accident occurred, but not the casualties' places of residence. Among those involved in an accident at a certain place there may obviously be some non-residents, such as in-commuters and transients. Hence spatial analysis based on place of accident may not be suitable for drawing conclusions about specific risk levels for people living in certain places. People's risk of encountering an accident in areas other than that where they live may vary with their mobility.

We report on two case studies for the German states of North Rhine-Westphalia and Lower Saxony, which are based on casualties' places of residence. We draw on two data sets both of which have specific advantages and disadvantages. From the data we calculate population-based risk figures on the district level and, for Lower Saxony, on the municipality level. For North Rhine-Westphalia these are categorised by age group and transport mode. We also investigate to what extent accident related analyses can be used to estimate residential related risks. The results show that the risk of being killed or seriously injured in a road accident is considerably lower for the population of agglomeration cores than for the suburban and rural population. Macro-economically this means that suburban and rural areas have markedly higher accident costs than cities.

key words: traffic safety, traffic accidents, residential location, built environment

1 Introduction

Providing a safe environment for their children has been recognised as being a major concern of parents in their residential choices, and a potential driver of household suburbanisation (Hillman, Adams and Whitelegg, 1990; Karsten, 2002). There is a general perception that cities are characterised by a lack of traffic safety, particularly for children, and this is supported by work that has found higher accident risks in cities than in rural areas. However, this is due partly to the use of inappropriate indicators. For instance, Klein and Löffler (2001) related accident counts to road space (accident density) instead of population, resulting in lower risk figures for rural areas due to the low traffic density in such areas.

A second reason for the seemingly lower safety levels in cities is the conjoint study of all casualties, no matter whether fatalities, serious or slight injuries. Such figures are relatively high in cities but they are strongly dominated by a large number of slight injuries.

A typical indicator of population-based risk figures is number of casualties in an area per 100,000 inhabitants. This indicator, however, does not show whether living in the city is safer or less safe than living elsewhere. This is because data used in road accident studies has typically referred to place of accident rather than place of residence. Among those involved in a crash at a certain place there may obviously be some non-residents, such as in-commuters and transients. As residents of any one municipality may be exposed to accident risks in other municipalities to varying extents dependent on their mobility, studies based on crash location do not allow conclusions to be drawn about the accident risk levels of residential populations.

This paper studies the spatial distribution of road accident risks associated with choice of place of residence. We report on two case studies for the German Federal States of North-Rhine Westphalia and Lower Saxony. We also investigate the suitability of crash location-based analyses for estimating residential related risks. To the best of our knowledge, this is the first study for Germany apart from our own pilot study (Holz-Rau and Scheiner, 2009) that relates accident risk to place of residence rather than place of accident.

The research is drawn from a project that examined residential location information for house-hunters in two pilot cities (Holz-Rau et al. 2010)[1]. The advantages and disadvantages of living in the cities compared to their suburban fringes were seen to be central for the households, with road accident risks being an important factor.

2 Research background

Studies on geographical variation in traffic safety have been relatively rare. Overall, results have tended to claim that high density and urbanity are associated with a lower risk of severe injuries or even lower total accident risks. For instance, Ewing et al. (2003) found a negative association between density and fatalities per inhabitant in a study of 448 counties in the USA. This applied to all casualties taken together as well as for pedestrian casualties, amount of pedestrian travel (acting as a proxy for pedestrian risk exposure) was controlled. Dumbaugh and Rae (2009)

[1] "Integrated Residential Location Information as a Contribution to Reduce Land Consumption" (2006-2010). Project partners: Technische Universität Dortmund, Department of Transport Planning (coordination); Technische Universität Dortmund, Institute of Spatial Planning; Büro für Integrierte Planung Berlin; plan-werkStadt, Bremen; Stadt Wilhelmshaven; Landeshauptstadt Schwerin; DV – Gesellschaft des Deutschen Verbandes für Wohnungswesen, Städtebau und Raumordnung mbH, Berlin. Funded by the German Federal Ministry for Education and Research (BMBF) within the framework of the programme 'Research for the Reduction of Land Consumption and for Sustainable Land Management' (REFINA). See http://www.vpl.tu-dortmund.de/cms/en/Research/index.html for further information.

studied accident counts for San Antonio, USA, on the neighbourhood level. They controlled for size, population density, and socio-demographic and traffic infrastructure attributes of the neighbourhoods, and found that large-scale retail outlets were associated with increased risk of accident and injury, while the opposite was true for traditional designs with high density, walkability and small-scale neighbourhood shops. They interpreted these findings as resulting from higher speed levels on arterials and less driving in traditional neighbourhoods.

Noland and Quddus (2004), in a study of 8414 wards in England, found a lower absolute number of casualties and particularly fatalities in urban areas with higher densities, but a higher number of casualties in areas with higher workplace densities (similarly: Levine et al., 1995, for Honolulu). In this study the authors controlled for area size and population size, demographic structure, urban structure and transport infrastructure.

In general, the reasons for such differences may involve three interdependent realms: (1) risk exposure, (2) environment, (3) social and psychological factors. Risk exposure is mainly an outcome of motorisation, transport mode use and travel distances. In terms of severity of accident, driving speeds are of major importance as well. These again depend on road type and design. Environmental factors include the condition of the road network, spatial context (e.g. density and land-use; plantation etc.) and transport context (traffic density, behaviour of other transport users). Social and psychological factors include sociodemographic structures, risk attitudes, lifestyles and 'mobility styles' (Schulze, 1999). For instance, in a questionnaire survey in Norway of 900 young adults Eiksund (2004) found that risk acceptance and risk-seeking were more common in rural areas than in urban areas. This finding is supported by Levine et al. (1995) who attributed the stronger severity of accidents in suburban and rural – as compared to urban – areas in Honolulu (USA) to more frequent night driving and alcohol consumption.

In Germany Apel et al. (1988) performed an accident analysis in 80 cities with over 60,000 inhabitants. They found that compact, dense cities were associated with lower accident risk and ascribed this to lower per capita travel volume, i.e. to risk exposure. What is more, they found that accident risk increased with a higher degree of road network extension (road length divided by population plus in-commuters), a higher motorisation rate, and greater use of the private car. Meewes (1984) found similar results for towns and municipalities with less than 80,000 inhabitants. However, neither of the studies allowed comparisons to be made between large cities, smaller settlements and more rural municipalities.

Neumann-Opitz et al. (2008) found higher risk figures for children aged 14 or under in German cities than in rural or suburban districts. Their findings also showed spatial differences according to transport mode. The risk of having an accident as a pedestrian increased with municipality size, while the opposite was true for vehicle occupants. Accident severity was, however, not considered and the large number of slight injuries therefore dominated the overall picture.

All studies shared a common characteristic. The data used referred to place of accident and did not consider the casualties' places of residence. It was therefore impossible to draw conclusions about the geographically specific accident risks of different residential populations, even though some findings implicitly used place of accident as a proxy for place of residence.

Holz-Rau and Scheiner (2009) in a pilot study analysed the Lower Saxony data used in this paper. These data were categorised by place of residence. They found considerably lower risk figures for city dwellers than for rural and suburban populations. However, analyses were limited to a simple spatial categorisation. Donaldson et al. (2006) also considered place of residence in their Utah study but did not attempt to produce population-based risk figures for place of residence. They investigated combinations between place of accident and place of residence for vehicle occupants in binary categories of urban versus rural.

3 Methodology

Official German accident data record place of accident on the municipality level (or the district level, depending on the Federal State), but not casualties' places of residence. For two reasons this makes the estimation of population-based risk figures difficult. On the one hand, the risk of being injured outside the municipality where one lives may be particularly high in out-commuting municipalities. Risk figures based on place of accident may thus underestimate the risk for the residential population of out-commuting areas (i.e. particularly small municipalities), and overestimate the risk for residents of in-commuting areas (large cities). On the other hand, severe accidents are largely concentrated on country roads and federal highways, roads that sometimes have relatively low construction standards but high traffic speeds. This means that crash location-based risk figures may overestimate risks for rural populations, because casualties on such roads may include considerable numbers of city dwellers.

This paper is based on two data sets suitable for consideration of place of residence. We start with an analysis of North-Rhine Westphalia (NRW) on the district level and continue with a second case study of Lower Saxony (LS) on the municipality level, complemented by findings for the district level. In the following, we briefly introduce the study areas and the data.

3.1 Study areas

Both NRW and LS are located in north-west Germany and are among Germany's largest federal states (Figure 1). NRW is divided into 54 districts and cities with a mean area of 631 km², LS is split into 46 districts and cities with a mean size of 1,035 km². Cities are for practical purposes 'urban districts' but they are actually known as 'district-free cities' (*kreisfreie Städte*) and typically include agglomeration cores, i.e. large cities with about 100,000 inhabitants or more. Districts (*Landkreis*) include suburban and rural areas. We use the terms 'district' and 'district level' to include 'district-free cities'.

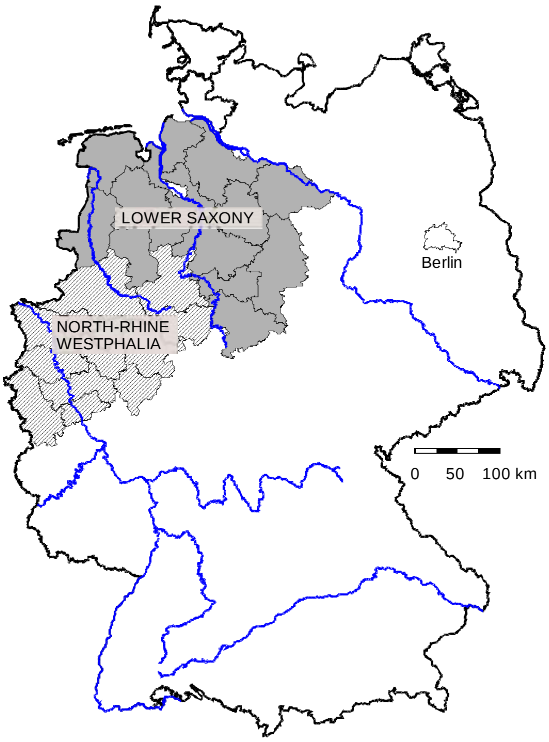

Figure 1: Location of the study areas in Germany

Source: authors' concept.

NRW is strongly urbanised with the highest population density of all German federal states (528 inh/km²) except for the city states of Berlin, Bremen and Hamburg (Table 1). In terms of population NRW is the largest German state with almost 18 million inhabitants. The Rhine-Ruhr region, a cluster of cities at the centre of NRW, is the largest population agglomeration in Germany. Only 13 percent of NRW municipalities have fewer than 10,000 inhabitants, compared to 87 percent in the whole of Germany.

LS has a very low population density of 167 inhabitants per km², well below the German average. The state is very rural with some industrial areas. The state capital of Hannover has about 520,000 inhabitants and is by far the largest city in LS, followed by Braunschweig with slightly less than 250,000 inhabitants. There are seven more cities with 100,000-250,000 inhabitants. 80 percent of all municipalities have populations of fewer than 10,000, while just under 50 percent have less than 2,000 inhabitants.

In LS there are a large number of unincorporated areas that are not affiliated to any municipality, particularly in the mountain ranges of Harz and Solling, and in the Lüneburg Heath. These areas appear on maps as empty spaces. Furthermore, the city state of Bremen forms an enclave in LS, including its own exclave of Bremerhaven.

	North-Rhine Westphalia	Lower Saxony	Germany
area (1,000 km²)	34.086	47.625	357.104
population (millions)	17.997	7.972	82.219
density (inhabitants/km²)	528	167	230
cities > 250,000 inh (no.)	13	1	27

Table 1: The study areas: basic figures (2007)

Source: Destatis (Federal Statistical Office).

3.2 North Rhine-Westphalia data

The data used for the two case studies each have their own advantages and disadvantages (Table 2).

	North-Rhine Westphalia	Lower Saxony
Spatial resolution	53 districts and cities	1,024 municipalities
Travel mode	yes	no
Age groups	yes	no
Accuracy of residence attribution	lower (motor vehicle: license number; pedestrians and bicyclists: place of accident)	high
Observation years	1998-2008	2006-2008
Combination between place of residence and place of accident	yes	no

Table 2: Attributes of data used

The place of residence of casualties is not recorded in official German statistics. In NRW they are not coded digitally at all. We therefore used vehicle license numbers, which indicate the district where the vehicle is registered, as a proxy. This provided a relatively rough spatial resolution based on the 54 districts. As the district of Aachen and the city of Aachen have the same number plate, they were treated as one district. 53 spatial units were thus used in the analysis. Using number plates means data may be slightly biased, as not all vehicles are registered at the occupants' places of residence (casualties may be passengers or the vehicle in question may be rented or a company car).

The data included all casualties on any road type from 1998 to 2008. They were classified by age groups (0-5, 6-14, 15-17, 18-20, 21-24, 25-64, 65+) and severity of injury. They included roughly 707,200 cases with an identifiable vehicle license number. 6 percent are out-of-state plates.

We geographically classified injured pedestrians and bicyclists by place of accident, as they do not have number plates. This is a sufficient proxy for the place of residence in these cases (see Sections 4.1 and 5.1). Non-motorised trips are generally short trips. For instance, motorised modes are even used for the majority of trips between 1.0 and 1.5 km in Germany (Scheiner, 2010)[2].

The data did not include accidents involving NRW inhabitants outside the state borders. The real risk figures are therefore higher than those calculated in this study. The municipality level data for LS showed that this underestimation is limited to a narrow belt of not more than 5 km along the state border (see below). On the district level this is hardly relevant, so we refrained from any correction.

In addition to the accident data we examined the following structural attributes of the districts to determine whether these help explain accident risks and improve understanding of spatial differences. The selection of attributes was based on the literature (see Section 2), but also on data available in the regional data base of the NRW Statistical Office. We used the mean values of the years 1998 to 2008, except where noted.

- Compactness: share of settlement and transport areas in total district area
- Extension of road network: share of road space in total district area
- Population density: 1,000 inhabitants per km²
- Motorisation rate: passenger cars per 1,000 inhabitants
- Workplace centrality: ratio of work places (subject to social insurance contribution) to residential population
- Demographic structure: shares of age groups among the population
- Socio-political climate: share of Green voters at the 2005 federal election.

The latter attribute may sound somewhat unusual. We assumed that dominant attitudes towards (transport) policy in an area may play an important role for traffic safety. However, this is difficult to reflect in standardised data. Of all the German political parties of a noteworthy size, the Green party is the only one that advocates a specific transport policy different from that of all other parties. Kahn and Morris (2009) found that share of Green voters significantly affected travel behaviour in a municipality. However, we are not aware of any studies using share of Green voters in the context of traffic safety.

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[2] The NRW districts have a mean size of 631 km². This is equivalent to a circle with a radius of 14.2 km. Assuming a homogeneous population distribution, the mean distance an inhabitant has to cover to access the nearest district border is 4.15 km. 91 percent of all non-motorised trips in Germany are shorter than this distance (authors' calculation from *Mobilität in Deutschland* data 2002). This may serve as rule of thumb evidence that less than every tenth non-motorised trip crosses a district border. Even allowing for the fact that people may be injured or killed as pedestrians on trips by car or by train (after leaving the vehicle at the destination), the district where the accident takes place is very likely to match the district of residence.

Unfortunately we did not have any regional transport demand data that could reflect risk exposure. We used motorisation, which is closely connected to car use, as a proxy. Neither did we have data on operational speed levels. The general speed limit in Germany is 50 km/h within and 100 km/h outside built-up areas. It thus seems likely that mean operational speed levels are extremely closely and negatively correlated with compactness and that introducing a measure of operational speed levels would not substantially change the structure and results of the analysis.

	min	max	mean	standard deviation
	Lower Saxony municipalities (n=1,024)			
number of inhabitants (ln)	5.71	13.16	7.97	1.27
Socio-political climate (Green voters)	0.01	0.22	0.06	0.03
Motorisation rate	0.14	0.90	0.57	0.06
Aged 18-24 (proportion)	0.02	0.20	0.07	0.01
Aged 65+ (proportion)	0.09	0.42	0.20	0.04
	Lower Saxony districts (n=47)			
Compactness	0.08	0.67	0.19	0.14
Socio-political climate (Green voters)	0.02	0.22	0.08	0.05
Motorisation rate	0.42	0.69	0.54	0.05
Aged 18-24 (proportion)	0.07	0.10	0.08	0.01
Aged 65+ (proportion)	0.15	0.26	0.21	0.02
	North-Rhine Westphalia districts (n=53)			
Compactness	0.11	0.75	0.36	0.18
Socio-political climate (Green voters)	0.04	0.15	0.07	0.02
Motorisation rate	0.45	0.61	0.53	0.04
Extension of road network	0.02	0.12	0.06	0.03
Population density	0.13	3.35	1.09	0.91
Workplace centrality	0.20	0.59	0.31	0.07
Aged 18-24 (proportion)	0.07	0.09	0.08	0.01
Aged 65+ (proportion)	0.15	0.22	0.18	0.01

Table 3: Descriptives of explanatory variables used in regressions

Table 3 shows descriptive statistics of the explanatory variables finally used for the regression models (see results section).

3.3 Lower Saxony data

Our data for LS are classified by the place of residence of the casualties. These are recorded by postal codes that may easily be recoded into municipalities. The data comprise the number of fatalities, severe injuries and slight injuries in the years 2006 to 2008 on any road category. A longer observation period is not available at this time.

The data include roughly 139,500 casualties. 3,800 of these cases (2.7 percent) remain unconsidered because the place of residence is abroad or cannot be assigned correctly. Of the remaining 135,755 cases, 122,908 individuals (90.5 percent) are resident in LS.

Again, real risk figures are underestimated as the data do not include accidents involving LS inhabitants that occur outside the state borders. This is particularly the case for municipalities located close to the state border. Table 4 suggests that the underestimation is limited to a narrow 5km-wide belt along the border, so we corrected the risk figures in these municipalities using the correction factors shown. In order to isolate the effect of distance from the border, we used a standardised weighting to adjust for differences in municipality size distributions in the various distance categories. The values thus slightly differ from the results presented below.

Distance from the border	fatalities	severe injuries	slight injuries
<= 5 km	5.6	70	355
5-10 km	7.9	81	411
10-15 km	7.6	77	395
15-20 km	6.5	78	421
> 20 km	7.0	79	456
overall	6.9	77	425
correction factor			
<= 5 km	1.2	1.1	1.2
other distance categories	1.0	1.0	1.0

Table 4: Fatality and injury risk in road traffic in Lower Saxony by distance from the state border

All values per 100,000 inhabitants, 2006 to 2008.
Source: authors' analysis. Data: LS Ministry of the Interior

As in NRW the accident data are complemented by structural attributes of the districts (and the municipalities) in order to study to what extent these contribute to the explanation of accident risks. The temporal reference complies with the accident data.

3.4 Analysis

Our approach was fairly straightforward. We estimated population-based risk figures for fatalities, severe injuries and slight injuries per 100,000 inhabitants. We did not consider road category or accident site (inside/outside built-up area). In NRW our figures were classified by age and travel mode. We complemented these figures by calculating macro-economic accident costs. This conforms to the sum of fatalities and injuries, weighted by severity. We used the standard unit costs used in cost benefit analysis in German transport planning (BASt 2006). They amount to 1,162 m € for fatalities, 87,269 € for severe injuries, and 3,885 € for slight injuries. We considered only bodily injuries and excluded vehicle damage. Our calculations therefore tend to slightly underestimate geographical differences, because vehicle damage tends to be more expensive in serious accidents.

Because of the relatively small number of severe injuries and fatalities we aggregated the data over the observation periods in order to level out random variance. That is to say, we did not aim to study trends.

		North-Rhine Westph.			Lower Saxony		
District type	criteria	no. of districts	inh (m)	inh (%)	no. of districts	inh (m)	inh (%)
agglomeration cores ('core cities')	'urban district', > 100,000 inh	22	7.2	39.9	6	1.3	16.5
high-density suburban districts	> 300 inh/km²	16	6.6	36.8	0	0.0	0.0
medium-density suburban districts	> 150 inh/km²	12	3.6	20.0	17	3.3	40.9
rural districts	< 150 inh/km²	3	0.6	3.5	24	3.4	42.6
all		53	18.0	100.0	47	8.0	100.0

Table 5: District types in the study areas

Based on the district typology of the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR, see www.bbsr.bund.de), simplified.

Our analysis began with descriptive spatial comparisons between district types (Table 5) plus, for LS, between the more finely grained municipality size categories. Over and above such typologies we mapped risk figures.

Besides descriptive analysis we asked which spatial attributes of the districts and municipalities contributed to the explanation of accident risks. We estimated OLS regression models for the total population and, in NRW, for three selected age groups. We focused on fatalities, severe injuries and accident costs.

Analysing spatial data means encountering two specific problems for which there is as yet no generally accepted solution. First, the modifiable area unit problem (MAUP), i.e. the effects of spatial aggregation on the observations (Openshaw, 1984). Second, the problem of spatial autocorrelation: as it can often be assumed that the observed values in a spatial unit are dependent on the values of the same variable in nearby spatial units, one deals, strictly speaking, with non-independent observations (Bivand, 2009). The impact of MAUP and spatial auto-correlation on the interrelation between the built environment and transport has been investigated (Bekhor and Prashker, 2008; Horner and Murray, 2002); however, these studies did not refer to traffic accidents.

Finding a solution to the MAUP and autocorrelation problems is beyond the scope of this study. However, in the municipality level models we handled spatial autocorrelation in a relatively simple manner by including accident risk values in directly adjacent municipalities as explanatory variables in the models, assuming zero correlation for municipalities that were not direct neighbours. We did not expect to encounter spatial autocorrelation on the district level due to the size of the districts, particularly as autocorrelation effects were seen to be weak even on the municipality level.

Also noteworthy is that the variance explanation rates in the municipality level models turned out to be close to zero. This was related to the spatial structure of LS being mainly rural with few large cities. If these few cities entered the analysis as single cases, the analysis was extremely dominated by small rural municipalities with more or less random differences within a relatively short observation period. For instance, there were 544 municipalities without fatalities. 531 of these (98%) had less than 10,000 inhabitants. However, almost all (90%) remaining municip-alities in this size category had higher than average fatality risk figures, reflecting the large variation in risk figures based on small population numbers. We therefore decided to undertake all regressions with data weighted by population size. We normed sample size to the real number of spatial units to avoid inflation of significance. The weight for the *i*-th spatial unit w_i was there-fore calculated using the following formula: $w_i = p_i / p * n$, with p_i being the population of the unit, p being the total state population, and n being the number of spatial units analysed. The weighting also considerably alleviated heteroskedasticity problems. Descriptive analyses are weighted as well.

4 Results for North Rhine-Westphalia

4.1 Is place of accident an appropriate proxy for residence-based risk?

Before turning to geographical distributions of risk figures, we consider whether place of accident may be used as an appropriate approximation of residence-based risk figures. If so, further research would be considerably facilitated owing to the easy availability of data referring to place of accident. Three key results for motor vehicle occupants are relevant:

(1) Among injured motor vehicle occupants just under two-thirds (64 percent) met with an accident in the same district in which they live. Among fatalities this figure is somewhat lower (57 percent). These figures were slightly higher among children, adolescents and the elderly both for fatalities and injuries. The share of accidents close to place of residence is likely to

be higher among pedestrians and bicyclists than among motor vehicle occupants. Our interest mainly focuses on *typical* spatial differences. Just under three-quarters (72 percent) of casualties met with an accident in the same district *type* as that in which they live. This figure was again somewhat lower among fatalities (66 percent).

(2) The residence-based risk figures on the district level were very strongly correlated with the risk figures based on place of accident. For fatalities the correlation was r=0.97, for severe injuries r=0.98, and for slight injuries still r=0.74. For all casualties taken together the correlation was r=0.84. This pattern was found for the separate age groups, with correlations ranging from r>0.65 to r=0.98. Accordingly, residence-based risk figures for motor vehicle occupants may be well approximated by risk figures based on place of accident. However, strong correlations do not make a residence-based analysis obsolete, as correlations do not permit conclusions on similar risk *levels*.

(3) The residence-based and place of accident-based perspectives may be compared between district types (Table 6). The absolute risk levels for the residence-based perspective were lower due to the exclusion of casualties from outside NRW. In order to facilitate comparison, we report percentage deviations for district types from the NRW mean values. The results show that the residence-based perspective decreased the spatial differences, particularly for fatalities and severe injuries. This suggests that the risk for city dwellers living in the agglomeration cores of being severely injured outside the city was larger than the risk for the suburban and rural population of being severely injured in the city. This reduces the strong spatial differences apparent in the accident-based perspective. However, in total the results show good consistency between the two perspectives.

	Fatalities		Severe injuries		Slight injuries		All casualties	
	resid-ence	place of accident	resid-ence	place of accident	resid-ence	place of accident	resid-ence	place of accident
agglomeration cores	-40%	-57%	-27%	-33%	-2%	2%	-7%	-5%
high-density suburban districts	6%	10%	5%	6%	4%	-2%	4%	-1%
medium-density suburban districts	56%	78%	33%	44%	-3%	-1%	3%	8%
rural districts	79%	126%	63%	85%	6%	5%	16%	20%
mean (NRW)	3.0	3.6	51	63	242	288	296	355

Table 6: Fatality and injury risk of motor vehicle occupants – deviations of district types from NRW mean. Comparison of place of accident-based and residence-based perspectives

All figures per 100,000 inhabitants (mean value for 1998-2008).
Source: authors' analysis. Data: IT.NRW

To sum up, these results suggest considerable consistency between place of accident-based and place of residence-based risk figures. However, the more finely grained the spatial level of analysis, the more this consistency is likely to decrease. The appropriateness of complementing our motor vehicle occupant data by crash location-based data for bicyclists and pedestrians is further supported by the fact that the total number of casualties was strongly dominated by motor vehicle occupants anyway, for whom we had place of residence information. This dominance becomes evident in the following.

4.2 Spatial differences – safe and less safe places of residence

Table 7 clearly shows that urban dwellers were considerably less at risk of being involved in an accident as a motor vehicle occupant than the suburban and rural population. This was particularly the case for fatalities and severe injuries, while the spatial variation was lower for slight injuries. This is likely to be associated with spatial variation in per capita vehicle miles travelled. Accordingly, this higher risk for suburban and rural dwellers is perhaps compensated by a higher risk for urban dwellers of meeting with an accident as a bicyclist or a pedestrian. However, there was only limited evidence for this 'compensation hypothesis' (Table 7):

- For bicyclists the risk of severe or fatal injuries was – contrary to the compensation hypothesis – below average in agglomeration cores and highest in medium-density suburban districts. For slight injuries agglomeration cores showed the highest (worst) value. However, there was little spatial variation in slight injuries except for rural districts, which performed clearly better than all other district types.

	bicyclists	pedestrians	motor vehicle occupants	sum
	Fatalities			
agglomeration cores	0.4	1.0	1.8	3.2
high-density suburban districts	0.5	0.8	3.2	4.5
medium-density suburban districts	0.9	1.1	4.7	6.8
rural districts	0.5	1.0	5.4	6.9
overall	0.6	0.9	3.0	4.5
	Severe injuries			
agglomeration cores	15	18	37	70
high-density suburban districts	16	12	54	83
medium-density suburban districts	22	11	68	101
rural districts	15	14	83	112
overall	17	14	51	82
	Slight injuries			
agglomeration cores	76	49	236	360
high-density suburban districts	69	32	252	353
medium-density suburban districts	73	23	234	330
rural districts	36	24	256	315
overall	71	37	242	350
	All casualties			
agglomeration cores	91	68	275	434
high-density suburban districts	86	45	309	440
medium-density suburban districts	96	35	306	438
rural districts	51	39	344	434
overall	89	52	296	437
	Macro-economic costs (m €)*			
agglomeration cores	2.1	2.9	6.3	11.2
high-density suburban districts	2.3	2.1	9.4	13.8
medium-density suburban districts	3.3	2.4	12.3	18.0
rural districts	2.0	2.5	14.5	19.0
overall	2.4	2.5	8.9	13.8

Table 7: Fatality and injury risk by district type in NRW

All figures per 100,000 inhabitants (mean values for 1998-2008).
Motor vehicle occupants coded by place of residence (vehicle license number), pedestrians and bicyclists by place of accident.
* Bodily damage (fatalities and injuries); unit costs taken from BASt (2006).
Source: authors' analysis. Data: IT.NRW

- For pedestrians, agglomeration cores performed clearly worse than other district types with respect to severe and slight injuries. This supports the compensation hypothesis. However, this was not true for fatalities. The risk of being killed in an accident as a pedestrian showed relatively little spatial variation.
- Only when all casualties were summed up, regardless of accident severity, could compensation between the transport modes be clearly seen. Using this sum almost completely levelled out spatial differences.

Taking crash severity into account, the risk of a severe or fatal injury increased steeply with decreasing population density (Table 7). For rural dwellers the risk of a fatal accident was about twofold higher (6.9 v. 3.2) than for city dwellers. For slight injuries, the reverse was true, although the spatial differences were less marked. Accident costs increased with decreasing density, and they were 70 percent higher in rural districts than in agglomeration cores.

It should not be forgotten that the spatial coding of pedestrians and bicyclists was based on the simplifying assumption that their district of residence and district of accident were identical. However, the spatial differences found here would change little even if we were able to code them according to place of residence, because severe risks were strongly dominated by motor vehicle occupants for whom the spatial differences were most striking.

	age group							
	0-5	6-14	15-17	18-20	21-24	25-64	65+	overall
	Fatalities							
agglomeration cores	0.8	1.1	2.0	4.9	5.1	3.0	4.8	3.2
high-density suburban districts	0.9	1.1	4.9	12.4	9.4	4.2	5.8	4.5
medium-density suburban districts	0.8	1.7	7.1	19.4	15.6	6.3	8.6	6.8
rural districts	1.2	1.8	7.4	24.4	15.4	6.9	6.3	6.9
overall	0.8	1.2	4.3	11.3	9.1	4.2	6.0	4.5
	Severe injuries							
agglomeration cores	37	78	84	149	127	68	55	70
high-density suburban districts	33	72	129	246	173	77	60	83
medium-density suburban districts	31	75	152	327	226	93	77	101
rural districts	42	83	194	427	268	101	67	112
overall	34	75	118	230	168	77	62	82
	Slight injuries							
agglomeration cores	155	381	448	854	734	381	160	360
high-density suburban districts	141	350	554	1029	792	348	163	353
medium-density suburban districts	118	305	524	1033	727	319	155	330
rural districts	129	265	472	1132	805	307	119	315
overall	141	348	504	963	757	354	159	350
	Macro-economic costs (m €)							
agglomeration cores	4.7	9.5	11.4	22.0	19.9	10.8	11.0	11.2
high-density suburban districts	4.4	8.9	19.1	39.9	29.1	13.0	12.6	13.8
medium-density suburban districts	4.1	9.7	23.6	55.1	40.6	16.7	17.3	18.0
rural districts	5.6	10.3	27.4	70.0	44.3	18.1	13.6	19.0
overall	4.5	9.3	17.3	36.9	28.3	13.0	12.9	13.8

Table 8: Fatality and injury risk by district type in NRW – age groups

All figures per 100,000 inh in the respective age group.
See remarks below Table 7.

Comparing age groups (Table 8) showed the well-known concentration of high risk among young adults: the risk virtually exploded at driving age and decreased again in the middle age group.

However, the spatial distribution suggests that this short-term 'risk summit' – although existent in all spatial environments – was far less pronounced in cities than in suburban and particularly rural districts (Figure 2). For instance, while the risk of a fatal accident increased through the life course from the age group 6-14 to the age group 18-20 by factor 4.5 in agglomeration cores (4.9 / 1.1=4.5), it increased by factor 13.7 in rural districts (24.4 / 1.8=13.7). Accident costs in the age group 18-20 were therefore threefold higher in rural areas than in agglomeration cores. For the middle-aged and the elderly the fatality risk was also higher in suburban and rural areas than in cities, reaching more than factor two for the middle-aged.

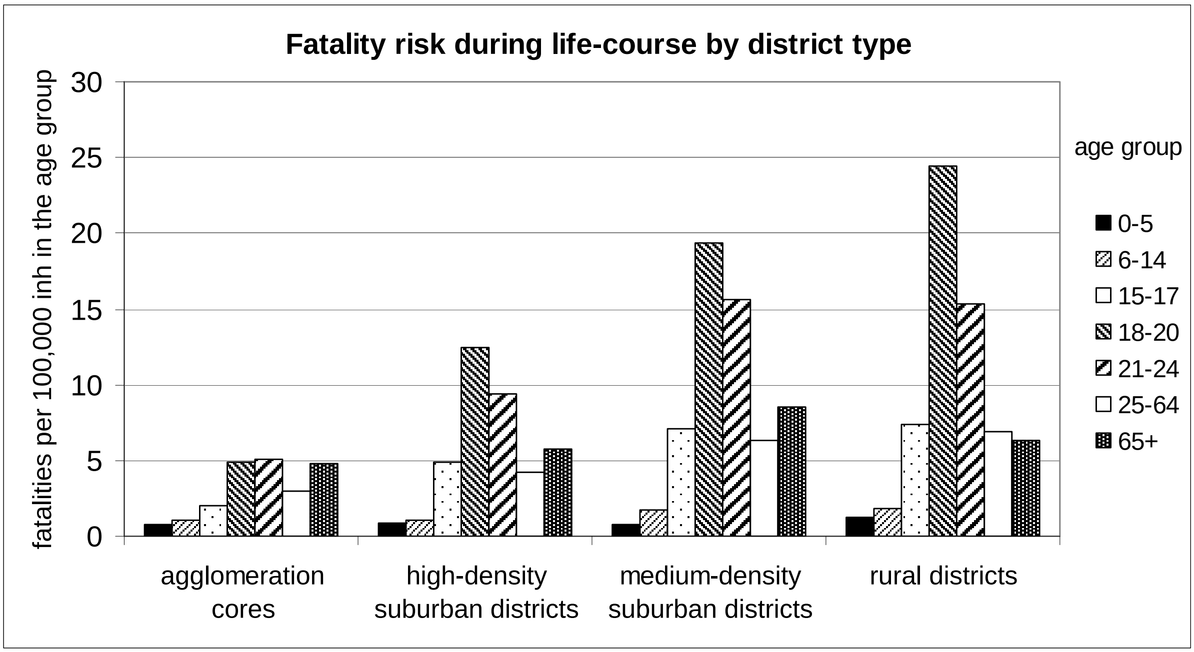

Figure 2: Fatality risk by district type in NRW – age groups

See remarks below Table 7.

Concrete spatial patterns are shown in Figure 3 to Figure 6. We focused on fatalities, because these relatively few accidents account for most human suffering and almost half the macro-economic cost (BASt, 2006).

The picture for the total population corresponded strikingly with the NRW urbanisation pattern. The Ruhr area, the Rhine chain with Düsseldorf, Cologne and Bonn, the urban triangle of Wuppertal, Solingen and Remscheid as well as the solitaires of Aachen and Münster showed the lowest risk values. Districts with medium risk figures gathered in the high-density suburban districts of the greater Rhine-Ruhr region as well as near Bielefeld and Siegen. High risk figures appeared in the rural areas.

For children the picture was more mixed (Figure 4). Low risk figures for children were found in many agglomeration cores as well as in some suburban and rural areas. Other agglomeration cores, such as Bielefeld and Dortmund, displayed high risk figures, but the same was true again for some suburban and rural areas. It is important to note that despite the high level of aggregation on the district level over a span of eleven years the values for children were based on small absolute numbers. The smallest values appeared in the districts of Höxter (six child fatalities), Rheinisch-Bergischer Kreis (eleven), Warendorf (eleven) and Bielefeld (twelve).

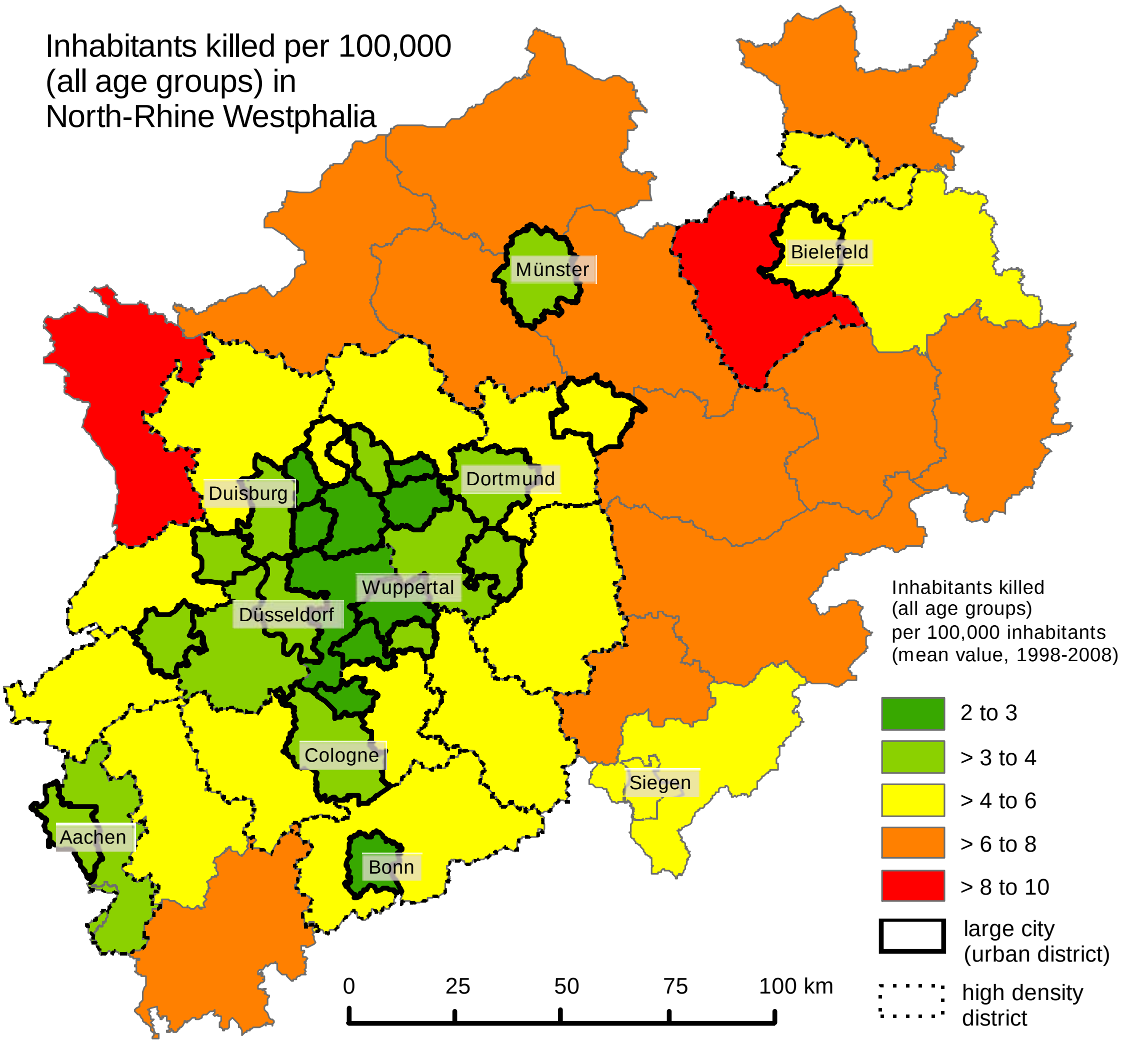

Figure 3: Fatality risk in NRW (all age groups)

See remarks below Table 7.

In the early years of driving (18-20) the urban-rural differences were found to be particularly blatant (Figure 5). The rural districts of Eastern Westphalia and other rural areas displayed risk figures five times higher than the Rhine-Ruhr agglomeration. The risk values among young adults were dominated by motor vehicle occupants even more than in other age groups. Nine out of ten fatalities in this group were motor vehicle occupants.

For the elderly the picture is again different (Figure 6). First, the risk in the age group 65+ was not focused on a certain transport mode. Only three of ten fatalities in this age group were motor vehicle occupants, four of ten were bicyclists, and three of ten were pedestrians. Secondly, the spatial differences were less pronounced. But the elderly, as other age groups, were generally found to live more safely in agglomeration cores than in the countryside. The best values appeared in the Rhine-Ruhr area, in the relatively urbanised districts around the Rhine-Ruhr, and in the smaller urban regions of Aachen and Siegen. The most unfavourable values appeared primarily in the rural northern parts of the state.

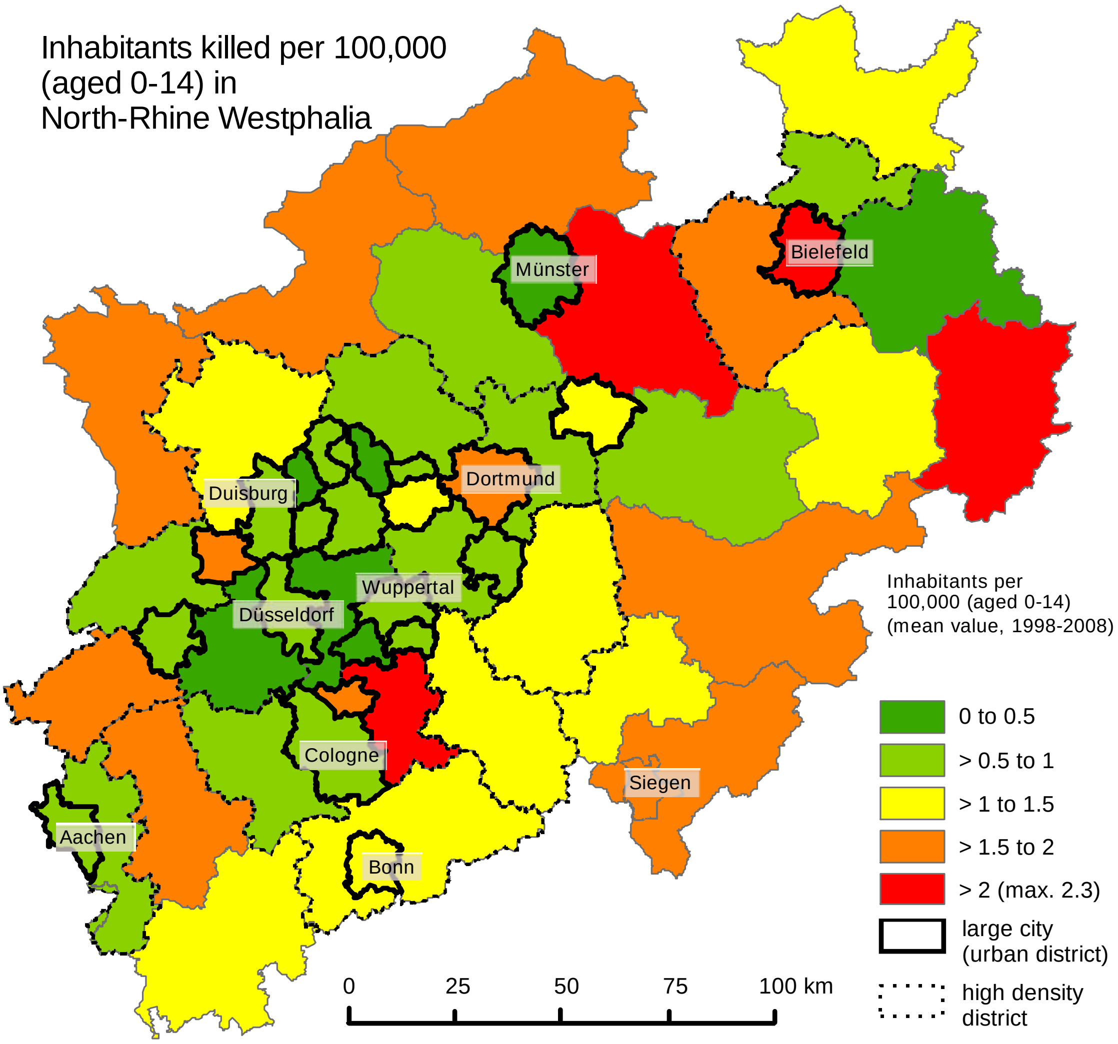

Figure 4: Fatality risk in NRW (aged 0-14)

See remarks below Table 7.

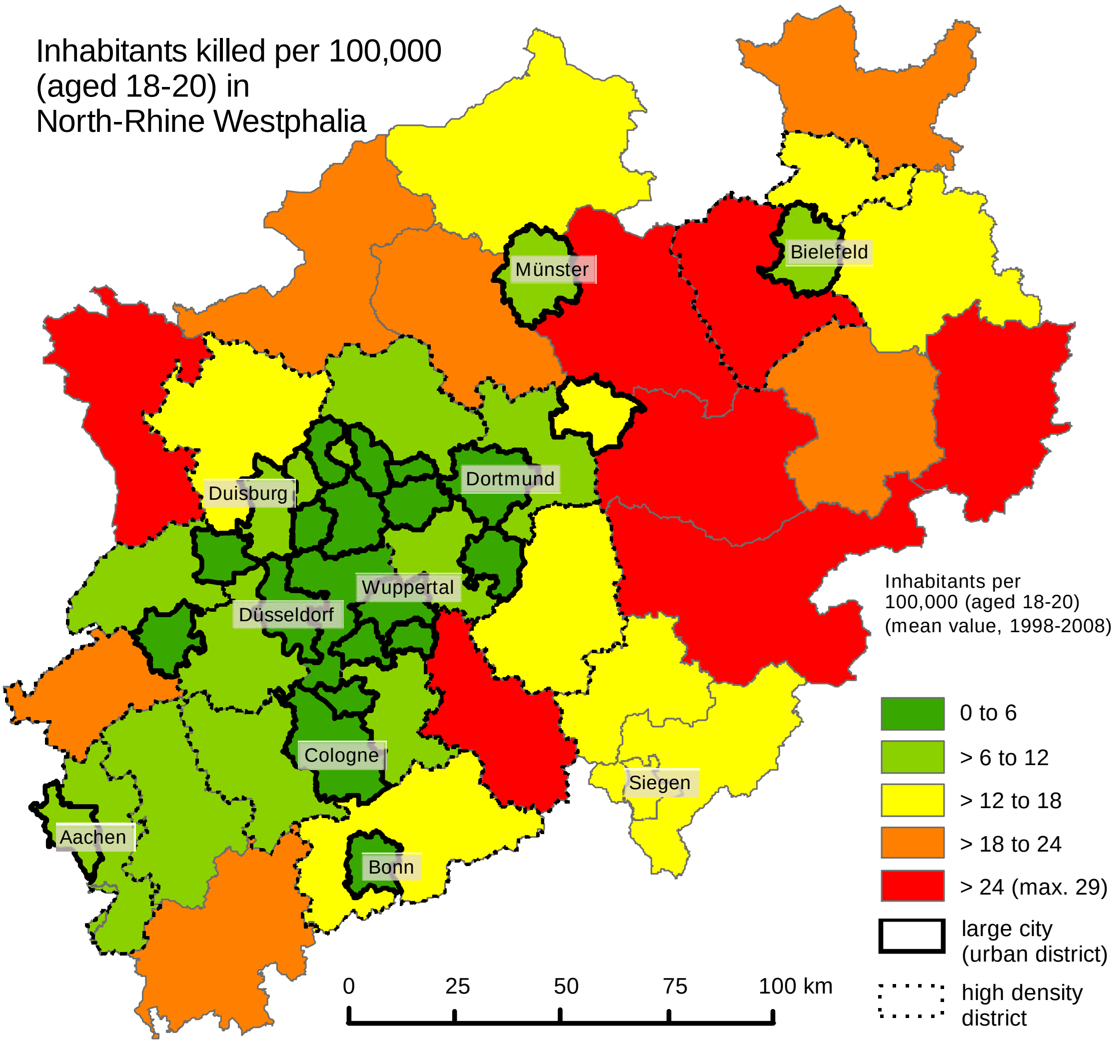

Figure 5: Fatality risk in NRW (aged 18-20)

See remarks below Table 7.

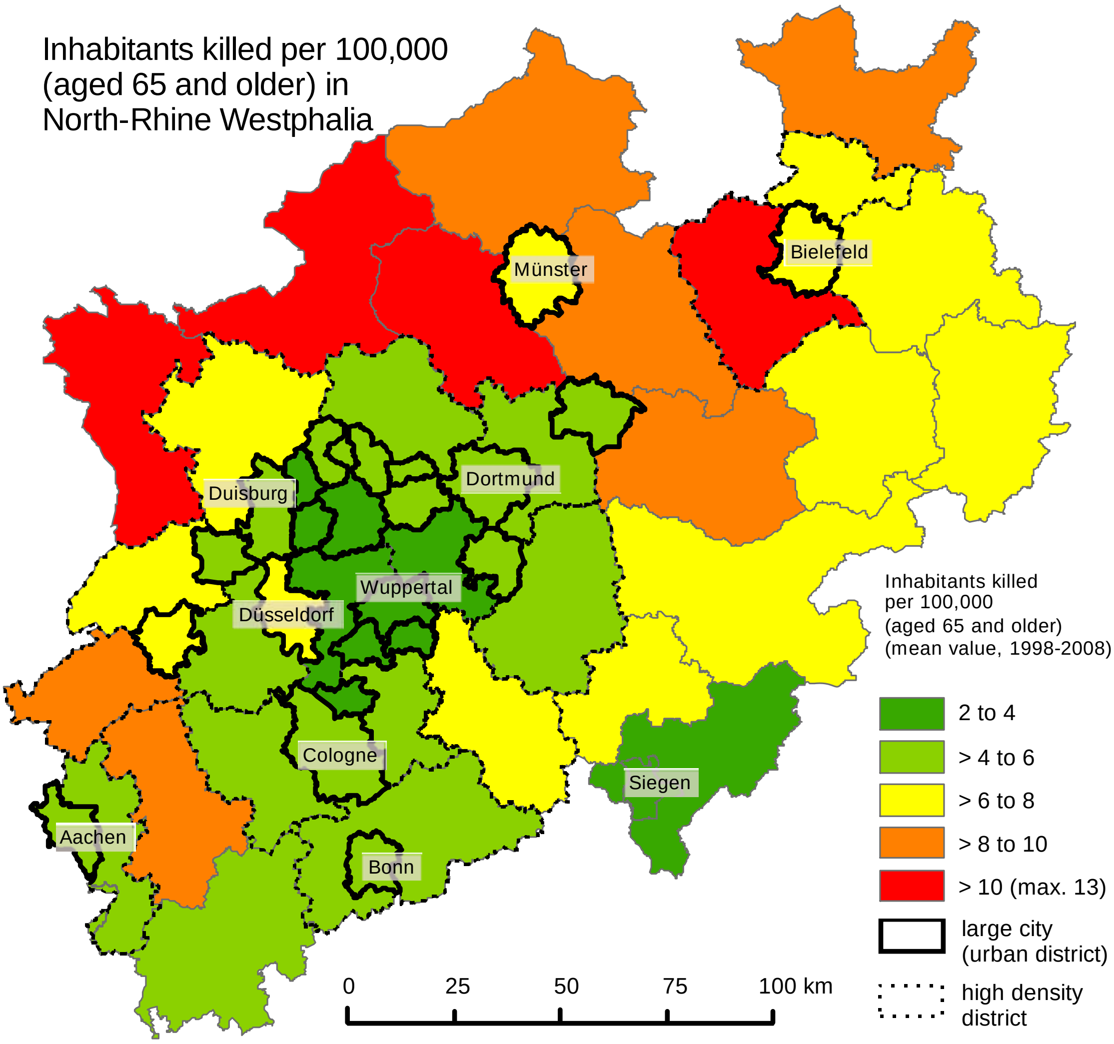

Figure 6: Fatality risk in NRW (aged 65 and older)

See remarks below Table 7.

4.3 Impact factors of accident risk – multivariate analysis

Building on the descriptive analysis above we now examine whether certain structural attributes of the districts (Section 3.1) may contribute to the explanation of spatial differences in accident risks. As the attributes are closely correlated with each other, we summarised them by using factor analysis.

The inclusion of the full set of age groups resulted in low discriminatory power and difficulties in interpretation of the factors[3]. Therefore we limited demographic structures to two age groups: those aged 18-24 and the elderly (65+ years of age). The former is known to be the main risk age group and the latter represents a vulnerable group of relatively slow drivers. We extracted our factors by using principal component analysis with varimax rotation. The Kaiser criterion (eigenvalue > 1) resulted in the three factors shown in Table 9. They explained 88 percent of the original variables' variance.

[3] Considering the full set of age groups led to three factors (Kaiser criterion). One factor represented a mix of socio-political climate plus a high share of the middle age group (aged 25-64). A second factor mixed a high motorisation level with a high share of the elderly. The third factor was very similar to the factor 'density and compactness' finally used, which is described below. We do not expect the reduction in complexity achieved by excluding some age groups to substantially affect our results, as the population age composition was well reflected in the indicators finally used.

The first factor was dominated by loadings of the variables compactness, population density, extension of the road network and (negatively) motorisation rate. This factor mainly represented the attributes of the 'classical' European city: density and compactness. It should be noted that extension of the road network does not represent car-oriented development patterns, but corresponds primarily with density. The Ruhr cities achieved high scores on this factor, while rural districts achieved low values.

	Density and compactness	Risk age group	Urbanity
Motorisation rate	-0.947		
Compactness	0.852	-0.424	0.245
Population density	0.845	-0.382	0.316
Extension of road network	0.838	-0.393	0.267
Aged 18-24 (proportion)		0.942	
Aged 65+ (proportion)	0.404	-0.757	
Workplace centrality			0.903
Socio-political climate (Green voters)	0.265		0.850

Table 9: Dimensions of the spatial structure of the NRW districts (factor analysis)

Values <0.20 suppressed.
See remarks below Table 7.

	Macro-economic cost (m €)		Fatalities		Severe injuries	
	B	p	B	p	B	p
	all age groups					
Constant	14.11	0.00	4.67	0.00	84.23	0.00
Density and compactness	-2.28	0.00	-1.11	0.00	-11.47	0.00
Risk age group	2.02	0.00	0.89	0.00	10.91	0.00
Urbanity	-0.88	0.00	-0.56	0.00	-3.03	0.05
R^2(adj)	0.72		0.69		0.68	
	aged 0-14					
Constant	7.67	0.00	1.11	0.00	61.24	0.00
Density and compactness	-0.02	0.92	-0.18	0.01	1.30	0.37
Risk age group	0.15	0.33	0.15	0.05	0.10	0.94
Urbanity	-0.15	0.36	0.00	0.98	-1.73	0.24
R^2(adj)	0.00		0.13		0.00	
	aged 18-20					
Constant	38.57	0.00	11.81	0.00	241.27	0.00
Density and compactness	-11.52	0.00	-4.79	0.00	-64.29	0.00
Risk age group	8.56	0.00	3.93	0.00	44.17	0.00
Urbanity	-5.93	0.00	-2.34	0.00	-34.21	0.00
R^2(adj)	0.70		0.60		0.71	
	aged 65+					
Constant	13.10	0.00	6.04	0.00	62.69	0.00
Density and compactness	-1.80	0.00	-1.03	0.00	-6.85	0.00
Risk age group	2.13	0.00	1.09	0.00	9.49	0.00
Urbanity	-0.25	0.53	-0.30	0.22	0.78	0.65
R^2(adj)	0.48		0.42		0.46	

Table 10: Impact factors of accident risk in NRW (regression models)

See remarks below Table 7.

The second factor represented demographic structures. It was characterised mainly by a high loading of the risk age group 18-24, while the elderly were negatively associated with this factor.

The third factor represented workplace centrality and socio-political climate. Again, both these variables have a close relationship with urbanisation. However, here urbanisation is less associated with the built environment than with the economy and public policy. We called this factor 'urbanity'. High urbanity scores were achieved by cities with strong economic power, welfare, universities (Bonn, Düsseldorf, Cologne) and/or solitary locations in a rural hinterland (Münster, Bielefeld). Low scores appeared in rural and suburban districts and smaller Ruhr cities, which are characterised by a mere agglomeration of population.

Our regression models were estimated for the total population and separately for all age groups included in the data. Three age groups were selected for presentation in this paper (Table 10): children (aged 0-14), adolescents (aged 18-20), and the elderly (aged 65+). The coefficients may easily be interpreted in terms of strength of impact as the factors used were standardised and therefore scale independent.

Variance explanation rates for the total population as well as for those aged 18-20 were very satisfactory. In the models for the elderly variance explanation was acceptable, while the models for children explained very little variance. We graphically checked heteroskedasticity by plotting residuals against estimated injury risks and found no reason to assume heteroskedasticity.

For all age groups the results consistently showed a significant, strong and negative relationship between the factor 'density and compactness' and accident risks. In only one of the models (severe injuries among children) is the sign in the opposite direction, but with a very weak, non-significant coefficient.

The factor urbanity reduced the risk of severe accidents as well, particularly for those aged 18-20 and for the population as a whole. Its impact was less marked than that of 'density and compactness'. Control analyses with original variables suggested that strong Green support had a stable impact in terms of lower fatality and injury risks. We did not assume strong Green political power, as the Green party holds a maximum of 15.2 percent (city of Cologne). Rather we interpreted this variable as a mix of car-critical *political* attitude and the relative dominance of an alternative, largely academic *social* milieu that is critical of risky driving and of the notion of the car being a status symbol giving certain privileges to its driver.

What is more, demographic structure had a strong impact on accident risks. A demographically young population structure, i.e. a high share of the high risk group aged 18-24 and a low share of those aged 65+, increased the risk figures considerably. This was not only due to the risk for the young adults themselves. Rather the risk of severe injury and fatality for the elderly and the fatality risk for children also increased with the share of young adults in the population. The impact of demographic structure was almost as strong as that of density and compactness. In the models for the elderly the effects of demographic structure even exceeded the effects of density and compactness.

Conclusions for NRW: Overall the strongest impact factors were found in the realms of the built environment and motorisation, plus demographic structure; the economic or socio-political (here: urbanity) seemed less important. A more detailed determination of relevant factors is not possible here, given the composite character of the factors.

5 Results for Lower Saxony

5.1 Is place of accident an appropriate proxy for residence-based risk?

As for NRW we first study the extent to which place of accident may serve to approximate residence-based risk figures. For LS our data did not include combinations of place of accident and residence. However, two observations are still noteworthy:

(1) The residence-based risk figures on the district level were strongly correlated with the risk figures based on place of accident. Unlike NRW, the correlations here were not limited to motor vehicle occupants, but included all casualties. For fatalities the correlation was r=0.74, for severe injuries r=0.79, and even for slight injuries still r=0.66. For all casualties taken together the correlation was r=0.47. The latter weak correlation may reflect typical spatial patterns of accident severity, with higher risks of fatalities and severe injuries in suburban and rural districts being partly offset by higher risks of slight injuries in cities. Generally, the coefficients were weaker than in NRW. On the municipal level the correlations were very weak and range between r=0.06 (slight injuries) and r=0.20 (fatalities). We suspect that this is because of the short observation period, which led to random variation particularly among small communities.

(2) As for NRW, residence-based and place of accident-based perspectives may be compared between district types and, additionally, between municipality size categories (Table 11). Again the residence-based perspective decreased the spatial differences. However, a few results went in the opposite direction. For instance, the above-average risk of a severe injury in the smallest municipalities was even stronger in the residence-based than in the place of accident-based perspective. In total, the results were again quite consistent between the two perspectives.

	Fatalities		Severe injuries		Slight injuries		Macro-economic cost (m €)*	
	resid-ence	place of accident	resid-ence	place of accident	resid-ence	place of accident	resid-ence	place of accident
> 500.000 inh	-40%	-63%	-35%	-41%	21%	44%	-32%	-44%
100-500.000 inh	-46%	-61%	-18%	-25%	1%	9%	-30%	-39%
50-100.000 inh	-32%	-54%	-11%	-23%	12%	11%	-19%	-35%
20-50.000 inh	-11%	-13%	-6%	-1%	0%	6%	-8%	-6%
10-20.000 inh	14%	25%	1%	5%	-6%	-12%	7%	13%
5-10.000 inh	19%	39%	4%	20%	-16%	-12%	9%	26%
<= 5.000 inh	67%	77%	45%	35%	3%	-20%	51%	50%
agglomeration cores	-41%	-61%	-25%	-31%	10%	22%	-29%	-40%
medium-density suburban districts	-16%	-7%	-6%	-5%	-2%	-4%	-10%	-6%
rural districts	31%	31%	15%	17%	-2%	-5%	21%	21%
overall	7.0	7.7	78	85	441	470	16.7	18.2

Table 11: Fatality and injury risk – deviations of municipality size categories from LS mean. Comparison of place of accident-based and residence-based perspectives

All figures per 100,000 inhabitants (mean values for 2006-2008).
All casualties coded by residence.
* Bodily damage (fatalities and injuries); unit costs taken from BASt (2006).
Source: authors' analysis. Data: Statistical Office LS (LSKN) and LS Ministry of the Interior

Once again the results suggest a considerable degree of consistency between place of accident and place of residence, but only on the district level. On the more finely grained level of municipalities correlations were weak. Thus, at this level of detail place of accident-based analysis should not be used to approximate residence-based risks. We assume that the relatively short period of observation and associated random variation contributed to the weakness of the correlations. Recording data over a longer period would be likely to improve reliability and perhaps result in stronger correlation.

5.2 Spatial differences – safe and less safe places of residence

Similarly to NRW, the risk of a severe or even fatal injury increased with decreasing population density (Table 12). In rural districts the risk of a fatal accident was more than twofold higher (9.2 v. 4.2) than in agglomeration cores. The risk of a severe injury was about 50 percent higher (90 v. 59). Conversely, the risk of a slight injury was 10 percent lower than in agglomeration cores. Accident costs reflected these differences; in rural districts they were 70 percent higher than in agglomeration cores. These findings matched the results for NRW perfectly.

	Fatalities	Severe injuries	Slight injuries	Macro-economic cost (m €)
agglomeration cores	4.2	59	487	11.9
medium-density suburban districts	5.9	74	434	15.0
rural districts	9.2	90	431	20.2
overall	7.0	78	441	16.7

Table 12: Fatality and injury risk by district type in LS

See remarks below Table 11.

District type	Municipality size	Fatalities	Severe injuries	Slight injuries	Macro-economic cost (m €)	Number of municipalities
agglomeration cores	> 500,000	4.2	51	533	11.4	1
	100-500,000	4.2	64	457	12.2	5
	overall	4.2	59	487	11.9	6
medium-density suburban districts	100-500,000	2.4	64	411	9.9	2
	50-100,000	4.5	66	498	12.9	6
	20-50,000	5.4	69	437	14.0	42
	10-20,000	6.6	73	423	15.7	57
	5-10,000	6.4	77	391	15.6	40
	2-5,000	8.3	78	308	17.6	65
	<= 2,000	11.3	130	612	26.9	141
	overall	5.9	74	434	15.0	353
rural districts	50-100,000	5.1	74	491	14.3	6
	20-50,000	7.4	80	444	17.4	31
	10-20,000	9.5	85	407	20.0	55
	5-10,000	9.4	84	361	19.6	83
	2-5,000	9.5	76	297	18.7	131
	<= 2,000	16.0	165	631	35.4	359
	overall	9.2	90	431	20.2	665

Table 13: Fatality and injury risk by district type and municipality size category in LS

See remarks below Table 11.

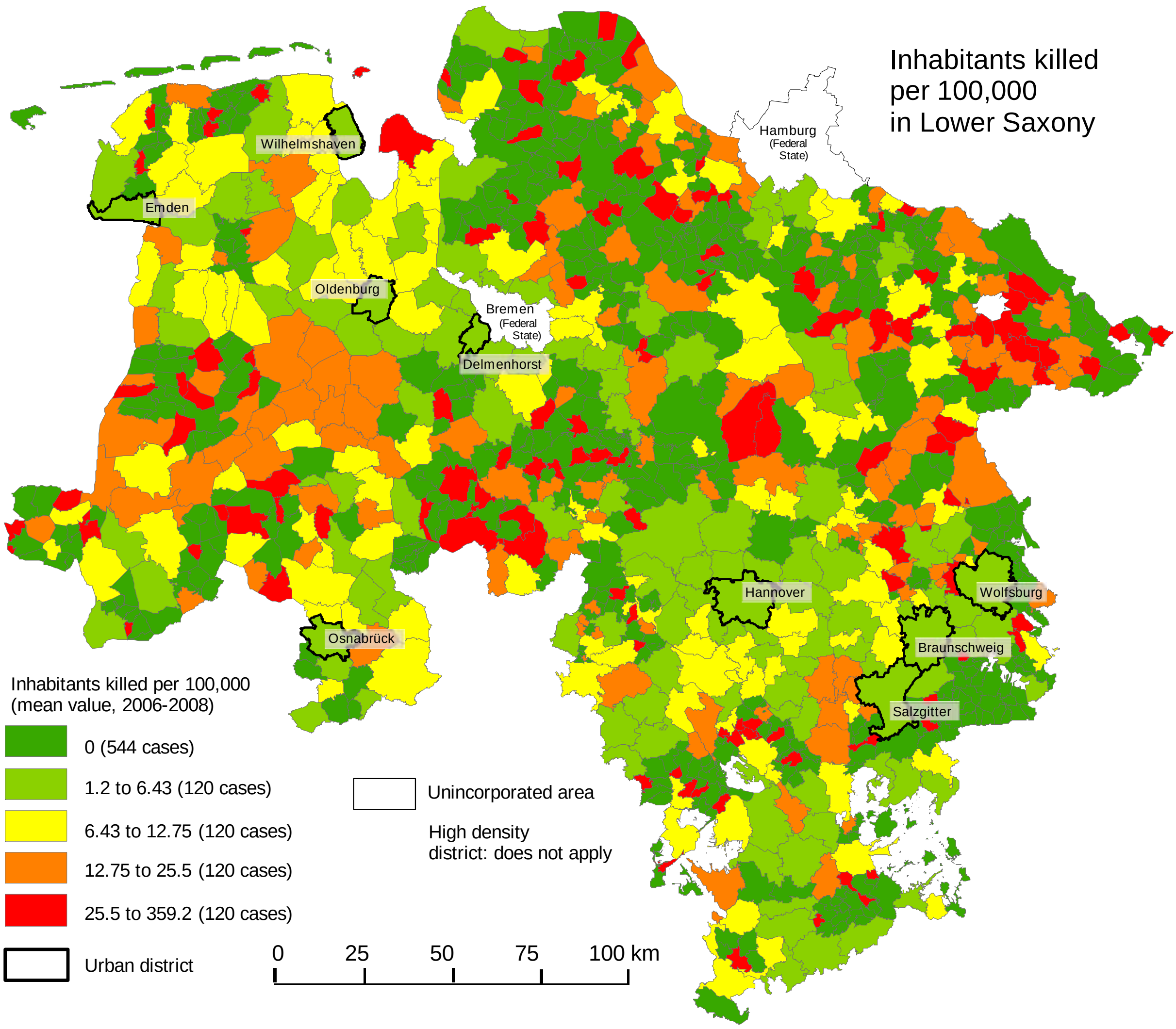

Figure 7: Fatality risk in LS (municipal level)

See remarks below Table 11.

Distinguishing between municipality sizes showed increasing accident costs, fatality risk and risk of severe injury with decreasing municipality size. The smallest municipalities (< 2,000 inh) appeared to be an extremely negative category. Conversely, the risk of a slight injury decreased with municipality size, but reached its maximum in the smallest municipalities. What is more, *within* a municipality size category rural districts performed even worse than municipalities of the same size in medium-density suburban districts. This may have to do with more risk-seeking among the rural population (Eiksund 2004) and/or with differences in road safety standards. The presumably more common use of country roads in rural areas rather than of the safer freeways and urban roads may play a role as well.

The spatial distribution of fatality risk (Figure 7) showed a patchwork pattern which was difficult to interpret. There were only a few clusters with high risk figures, e.g. in the Lüneburger Heath south east of Hamburg and in the Emsland between Osnabrück, Oldenburg and Emden.

The short period of observation led to severe inequalities at this detailed spatial level. As noted above, there were no fatalities in 544 municipalities (53 percent). This distribution did not allow reasonable mapping on the basis of equal class widths. We therefore used quintiles as categories (making an exception for the zero category whose large number of cases exceeds a quintile).

As seen on the map, all cities with urban district status were found to be relatively safe places of residence, as in NRW. None of the cities fell into the safest category, but all were in the second safest class. This included virtually all other relatively large cities (> 50,000 inh) without the urban district status (i.e. not *kreisfreie Städte*), such as Hildesheim, Göttingen, Lüneburg, Celle, and Cuxhaven. Zero fatalities appeared in a large number of smaller municipalities which partly cluster in a large ring south of Hamburg, between Hannover and Bremen, and east of Salzgitter near the Harz mountains. However, these ostensibly safe areas were scattered with municipalities with very high risk figures. Spatial interpretation is thus difficult.

Aggregation of results on the district level (Figure 8) showed a more distinct spatial pattern that resembled the NRW results. The larger cities (Hannover, Osnabrück, Braunschweig) belonged to the safest quintile, the smaller ones to the safest (Salzgitter, Delmenhorst) or second safest (Wilhelmshaven, Emden) quintile.

Among the suburban and rural districts, areas with relatively strong urbanisation tended to be in the medium or better categories. By contrast, the highest risk figures appeared in the low-density rural areas.

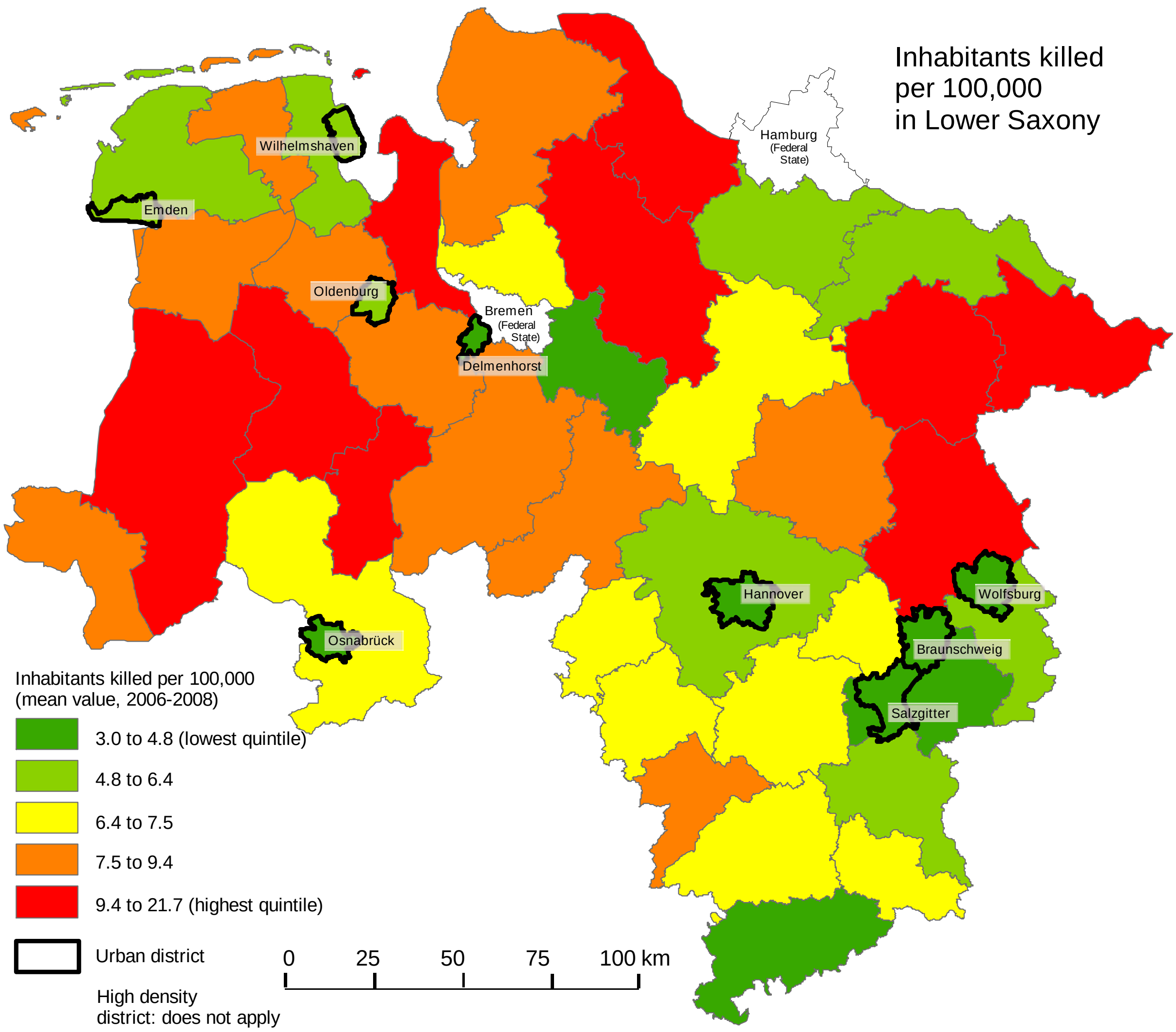

Figure 8: Fatality risk in LS (district level)

See remarks below Table 11.

5.3 Impact factors of accident risk – multivariate analysis for municipalities

In order to study accident risks using regression models, we started by applying factor analysis to the same structural attributes as in NRW. However, the factor structure turned out to be unsatisfactory, as demographic structure and motorisation stubbornly loaded on the same factor so that a high share of those aged 18-24 and a low share of those aged 65+ corresponded with low motorisation. Large cities tended to exhibit high factor scores, owing to students and other adolescents moving into them, but low motorisation rates. What is more, the use of factors yielded extremely low variance explanation rates in the regressions.

We therefore decided to use original variables as explanatory variables that permitted a more down-to-earth interpretation. Multicollinearity problems were less severe than in NRW. They appeared mainly between compactness, extension of the road network, population density, workplace centrality and number of inhabitants. Control analyses showed that among these attributes the number of inhabitants clearly contributed most to the explanation of accident risks. We therefore excluded the other variables from further analysis. We also took the natural logarithm from number of inhabitants due to the skewed distribution. Variance explanation rates achieved on the municipal level were nevertheless low, reflecting the spatial patchwork pattern in our maps (Table 14). As the magnitudes of the effects are scale-dependent, we report standardised coefficients too. Variance inflation factors in the models finally reported were generally very satisfactory (VIF<2.2) (Montgomery et al., 2001).

Scatterplots of residuals against estimated injury risks suggested heteroskedasticity, although the weighting scheme alleviated the problem considerably. We performed the Glejser test (Backhaus et al., 2000) in which the absolute residuals are regressed on the explanatory variables in question. This resulted in significant negative coefficients of municipality size, suggesting that the residuals were larger in smaller municipalities. Again this was due to the large number of zero cases ('no risk') in these municipalities, while other small municipalities exhibited particularly large risks. This means that the estimation may be inefficient and significance may be distorted. The results thus have to be interpreted with care.

This said, the results show that municipality size clearly had the strongest effect on accident risks among the variables under consideration. This effect was not very descriptive due to logarithmisation. Control analyses with municipality size classes showed that accident costs per 100,000 inh were 24-25 m € lower in cities with over 100,000 inh than in the smallest municipalities of less than 2,000 inh. The number of fatalities was 11-12 lower, and the number of severe injuries was 110 lower in cities of 100-500,000 inh, and 124 lower in cities larger than 500,000 inh (Hannover).

	Macro-economic costs (m €)			Fatalities			Severe injuries		
	B	Beta	p	B	Beta	p	B	Beta	p
Constant	60.89		0.00	32.30		0.00	236.02		0.00
Number of inhabitants (ln)	-3.51	-0.24	0.00	-1.72	-0.23	0.00	-16.65	-0.26	0.00
Motorisation rate	-17.17	-0.05	0.26	-9.74	-0.05	0.22	-65.91	-0.04	0.33
Aged 18-24 (proportion)	89.63	0.05	0.23	6.43	0.01	0.87	842.64	0.10	0.01
Aged 65+ (proportion)	-9.19	-0.01	0.73	-12.77	-0.03	0.36	109.47	0.03	0.37
Green voters	-28.56	-0.04	0.29	-12.79	-0.03	0.37	-166.23	-0.05	0.18
Risk in adjacent municipalities*	-0.15	-0.05	0.12	0.05	0.02	0.55	-0.39	-0.12	0.00
R^2(adj)	0.04			0.05			0.04		

Table 14: Impact factors of accident risk in LS on the municipality level (regression models)

* Risk figure according to the dependent variable
See remarks below Table 11.

Demographic structure was not significant, nor was motorisation rate, except in the model of severe injuries, in which the share of young adults (aged 18-24) increased the risk significantly. Spatial autocorrelation was relatively weak as well. Again, its effect was only significant for severe injuries. Contrary to intuition, this effect was negative. This means that the risk of severe injury tended to *decrease* with *increasing* risk in the neighbouring municipalities, underlining the spatial patchwork pattern noted above.

5.4 Impact factors of accident risk – multivariate analysis for districts

In order to perform the analysis on the district level multicollinearity was first considered again. The number of inhabitants on the district level does not satisfactorily reflect urban structure. Of the remaining strongly correlated attributes (see above), compactness performed better in terms of variance explanation than extension of the road network, population density and workplace centrality and was therefore used as the key indicator to reflect urban form. Using district type dummies led to considerably higher variance explanation than using metric indicators. However, using district type dummies along with metric indicators again posed multicollinearity problems. Thus, we present two model variants here. Variant 1 is based on metric variables, variant 2 is based on district type dummies. These district type models basically match the descriptive analysis above. We assumed zero spatial autocorrelation because of the rough spatial scale level and because autocorrelation was weak even on the municipality level.

The models performed better than those on the municipal level. Variance explanation rates ranged between 34 and 51 percent. Variance inflation factors were somewhat higher than in the municipality models, but were more than acceptable (VIF<2.8). As in NRW districts, we found no evidence for heteroskedasticity.

	Macro-economic costs (m €)			Fatalities			Severe injuries		
	B	Beta	p	B	Beta	p	B	Beta	p
Variant 1: metric attributes									
Constant	28.60		0.05	19.42		0.04	38.36		0.50
Motorisation rate	-4.09	-0.04	0.81	-2.26	-0.04	0.84	-7.18	-0.02	0.92
Compactness	-14.82	-0.54	0.00	-7.94	-0.47	0.01	-71.63	-0.63	0.00
Aged 18-24 (proportion)	83.07	0.16	0.32	9.92	0.03	0.86	833.96	0.38	0.02
Aged 65+ (proportion)	-50.14	-0.25	0.11	-43.01	-0.34	0.04	21.78	0.03	0.86
Green voters	-31.32	-0.34	0.01	-16.69	-0.29	0.03	-119.71	-0.32	0.01
R^2(adj)	0.40			0.34			0.42		
Variant 2: District type (Reference: agglomeration core)									
Constant	11.89		0.00	4.17		0.00	59.02		0.00
Medium-density suburban district	3.09	0.34	0.02	1.74	0.31	0.05	14.62	0.40	0.02
Rural district (urbanised region)	7.94	0.82	0.00	4.96	0.82	0.00	27.69	0.69	0.00
Rural district (rural region)	9.26	0.72	0.00	5.18	0.65	0.00	39.25	0.74	0.00
R^2(adj)	0.51			0.48			0.40		

Table 15: Impact factors of accident risk in LS on the district level (regression models)

See remarks below Table 11.

In model variant 1 compactness had the strongest impact on accident risk, followed by the share of Green voters. As elaborated upon above, increasing compactness was associated with more safety. From the district type models (variant 2) it became evident that even in medium-density districts the risk figures were significantly higher than in agglomeration cores. In rural districts of rural regions the risk situation was most dramatic. In these districts 5.2 more inhabitants per

100,000 were killed each year than in cities, and 39 more inhabitants per 100,000 were severely injured. Per capita accident costs in these districts were 9.3 m. € higher than in cities.

High shares of Green voters tended to be associated with markedly reduced risk figures as well. Demographic structure was significant in only two models. The share of the high risk age group 18-24 significantly increased the risk of severe injury. Conversely, a high share of the elderly reduced the risk of fatalities.

Conclusions for LS: The strongest impact factors were found to be in the realms of the built environment (compactness, city size) and socio-political context, somewhat complemented by demographic structures. Motorisation did not seem to play an important role.

6 Conclusions

This paper presented geographical analyses of road accident risks based on case studies for two German states. In our study, we did not spatially categorise casualties by place of accident, as is usual in accident analysis, but by their places of residence. In so doing, we estimated accident risk levels for the residential population in different built environments.

According to our results, the cliché of risky urban life is wrong. The risk of being killed or severely injured in road traffic is considerably lower for urban dwellers than for the suburban and rural population. Conversely, the risk of slight injuries is somewhat higher for the urban population. Urban dwellers have just as many – or even slightly more – accidents than countryside dwellers, but much less severe accidents. Differences in driving speeds are likely to play an important role here. Markedly higher per capita accident costs are thus seen in suburban and rural areas than in agglomeration cores. This key result is consistent for two German states on the basis of two data sets, both of which have specific advantages and disadvantages.

In NRW the validity of our data was limited, as we had to spatially assign pedestrians and bicyclists to crash locations. Our findings suggested that places of accident accord with places of residence to a considerable degree, at least at the relatively large-scale district level used here. The LS data did not exhibit many validity problems. However, reliability was limited due to the short period of observation available, leading to large random variation in risk figures, particularly for small municipalities.

For NRW our data included a breakdown by age group. Results showed that the enormeous age-related increase in the risk of a serious accident among adolescents and young adults was mainly concentrated in suburban and rural areas. This short-term 'risk summit' in the life course was far less pronounced in cities. What is more, in all age groups the fatality risk as well as the risk of severe injury was higher for the suburban and rural population than for urban dwellers. Some of the differences reached factor two or more. Only for children was the spatial picture less clear.

Our data did not permit an in-depth analysis of the reasons for our findings. Our multivariate analysis suggested density and compactness have strong effects, combined with a car-critical social milieu (Green voters). Particularly in NRW we also found marked demographic effects. However, the difficulties we encountered in constructing impact factors leave questions unanswered concerning the true explanatory variables. The effects of urban form are no doubt due also to reasons other than the urban form itself, for instance driving speed, behaviour, road design, or exposure. On the other hand, all these variables are themselves endogeneous to urban form.

We speculate that road accident risks were mitigated in cities by short trip distances, the more prevalent use of modes other than the car, and, most of all, lower driving speeds. Such 'prevention mechanisms' lead to lower risk exposure (as a car occupant) and less severe accidents.

These mechanisms exist outside the cities, if at all, only to a limited extent. They are particularly important for young adults. Temporal analysis of severe accidents among young drivers has shown that alcohol consumption, risk-seeking and leisure drives at night, particularly on Fridays and Saturdays, play an important role in this respect (Levine et al., 1995, Schulze, 1999). Public transport supply in cities encourages postponing learning to drive until older and means that motorisation remains at a lower level than outside the cities, which countervails age-related risks to a certain extent. For instance, Holz-Rau et al. (2010) found that only 23 percent of those aged 18-19 had instant access to a car to drive in German agglomeration cores, as compared to 42 percent in the suburban fringes. Among those aged 20-21 the respective figures were 33 percent in cities as opposed to 57 percent in the suburban fringe. Public transport also permits even those young (and other) people who have a car available to leave it at home in cases of foreseeable alcohol consumption. In this context the better availability of taxis and the lower cost of their use due to shorter trips in the cities are important factors as well. Last but not least, city dwellers make more trips than countryside dwellers on urban roads where driving speeds are lower.

Further research is required firstly in terms of other case studies in various spatial contexts. A more detailed spatial resolution of data would help improve our knowledge of factors contributing to the geographical distribution of population-based accident risks. The low variance explanation rates in our municipality level regression models suggest considerable uncertainty. Particularly for large cities an internal classification would be of interest in order to assess risk levels for central v. peripheral neighbourhoods, as there are typically sharp differences in terms of social and demographic structures, travel mode use, and centrality.

Secondly, further social differentiation of residence-based risk figures could contribute to a better understanding of risk involvement, e.g. by gender, ethnic status, car availability, and individual travel mode use. The high share of vehicle occupants among all casualties suggests that car use is of major importance for an individual's risk exposure. Individuals with low levels of car use in rural districts could be less at risk than frequent-driving city dwellers. One has to keep in mind the aggregate nature of our analysis and the associated risk of ecological fallacy. Low risk levels for an aggregate urban population do not necessarily imply low risk levels for any individual urban dweller.

In order to return to the subject of residential location information mentioned in the introduction, we can conclude from the findings presented here that there may be many reasons for a private household to leave the city and move to the suburban fringe. From a traffic safety perspective, however, households would be better advised to stay in the city. With respect to the high risk figures for adolescents and young adults in suburbia and in the countryside, this seems to be particularly evident for families.

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7 References

Apel, D., Kolleck, B., Lehmbrock, M., 1988. Stadtverkehrsplanung Teil 4: Verkehrssicherheit im Städtevergleich. Stadt- und verkehrsstrukturelle Einflüsse auf die Unfallbelastung. Difu, Berlin.

Backhaus, K., Erichson, B., Plinke, W., Weiber, R., 2000. Multivariate Analysemethoden. 9th ed. Springer, Berlin.

BASt (Bundesanstalt für Straßenwesen) 2006. Volkswirtschaftliche Kosten durch Straßenverkehrsunfälle in Deutschland 2004. BASt-Info 02/06. BASt, Bergisch-Gladbach.

Bekhor, S., Prashker, J. N., 2008. GEV-based destination choice models that account for unobserved similarities among alternatives. Transportation Research Part B 42(3), 243-262.

Bivand, R., 2009. Applying measures of spatial autocorrelation: computation and simulation. Geographical Analysis 41(4), 375-384.

Donaldson, A. E., Cook, L. J., Hutchings, C. B., Dean, J. M., 2006. Crossing county lines: The impact of crash location and driver's residence on motor vehicle crash fatality. Accident Analysis & Prevention 38(4), 723-727.

Dumbaugh, E., Rae, R., 2009. Safe urban form: revisiting the relationship between community design and traffic safety. Journal of the American Planning Association 75(3), 309-330.

Eiksund, S., 2004. Attitudes towards road safety and traffic behaviour among adolescents in urban and rural areas in Norway. Paper presented at the European Transport Conference, Strasbourg, France, 4-6 October, 2004.

Ewing, R., Schieber, R. A., Zegeer, C. V., 2003. Urban sprawl as a risk factor in motor vehicle occupant and pedestrian fatalities. American Journal of Public Health 93(9), 1541-1545.

Hillman, M., Adams, J., Whitelegg, J., 1990. One False Move… A Study of Children's Independent Mobility. Policy Studies, London.

Holz-Rau, C., Scheiner, J., 2009. Verkehrssicherheit in Stadt und (Um-)Land: Unfallrisiko im Stadt-Land-Vergleich. Zeitschrift für Verkehrssicherheit 55(4), 171-177.

Holz-Rau, C., Scheiner, J., Schwarze, B., 2010. Wohnstandortinformationen für private Haushalte: Grundlagen und Erfahrungen aus zwei Modellstädten. Dortmunder Beiträge zur Raumplanung – Verkehr. IRPUD, Dortmund (in print).

Horner, M. W., Murray, A. T., 2002. Excess commuting and the modifiable areal unit problem. Urban Studies 39(1), 131-139.

Kahn, M., Morris, E., 2009. Walking the walk: the association between community environment-alism and green travel behavior. Journal of the American Planning Association 75(4), 389-405.

Karsten, L., 2002. Mapping childhood in Amsterdam: the spatial and social construction of children's domains in the city. Tijdschrift voor Economische en Sociale Geografie 93(3), 231-241.

Klein, R., Löffler, G., 2001. Unfälle im Straßenverkehr. In: Nationalatlas Bundesrepublik Deutschland. Band 9: Verkehr und Kommunikation, Berlin, pp. 134-135.

Levine, N., Kim, K. E., Nitz, L. H., 1995. Spatial analysis of Honolulu motor vehicle crashes: I. spatial patterns. Accident Analysis & Prevention 27(5), 663-674.

Meewes, V., 1984. Sicherheitsdefizite in Städten und Gemeinden. Unfall- und Sicherheits-forschung Straßenverkehr 49. BASt, Bergisch-Gladbach.

Montgomery, D. C., Peck, E. A., Vining, G. G., 2001. Introduction to Linear Regression Analysis, 3rd ed., Wiley, New York.

Neumann-Opitz, N., Bartz, R., Leipnitz, C., 2008. Regionale Verteilung von Kinderunfällen in Deutschland – Kinderunfallatlas. BASt, Bergisch Gladbach.

Noland, R. B., Quddus, M. A., 2004. A spatially disaggregate analysis of road casualties in England. Accident Analysis & Prevention 36(6), 973-984.

Openshaw, S., 1984. The Modifiable Areal Unit Problem. Geobooks, Norwich.

Scheiner, J., 2010. Interrelations between travel mode choice and trip distance: trends in Germany 1976-2002. Journal of Transport Geography 18(1), 75-84.

Schulze, H., 1999. Lebensstil, Freizeitstil und Verkehrsverhalten 18- bis 34jähriger Verkehrsteilnehmer. BASt, Bergisch-Gladbach.