University of Natural Resources and Life Sciences, Vienna

Department of Economics and Social Sciences

University of Natural Resources and Life Sciences, Vienna

Lincoln University, New Zealand

Department of Environmental Management

Lincoln University
Te Whare Wānaka o Aoraki

Socio-spatial distribution of road traffic noise in Vienna, Austria

Master's Thesis (Joint Degree Programme)

Field of Study:

Natural Resources Management and Ecological Engineering

Supervisors:

Erwin Schmid, Univ.Prof. Dipl.-Ing. Dr. (Institute for Sustainable Economic Development, BOKU, Vienna)

Lin Roberts, BSc (Hons) Vic, PhD Auck (Faculty of Environment, Society and Design, LU, New Zealand)

Ulrich Morawetz, Dr. (Institute for Sustainable Economic Development, BOKU, Vienna)

Author:

Sandra Siedl, BSc (0752272)

25/01/16

Declaration

I hereby declare that this master's thesis titled "Socio-spatial distribution of road traffic noise in Vienna (Austria)" is my own work and all the sources cited in it are listed in the bibliography.

Vienna, 25 January 2016 Sandra Siedl

Acknowledgement

I want to express my sincere gratitude for the valuable advice and support provided by my supervisors during the work on this thesis. I have to thank Dr. Roberts from New Zealand for willing to join as co-supervisor. Although the huge distance in between, it always felt like she was living in Vienna. I am especially grateful for Dr. Morawetz and Prof. Schmid for suggesting him as Co- supervisor. His friendly support in particular on the data and methods section was invaluable for the completion of this thesis.

I also want to thank MMag. Wolfgang Remmel from MA 23 Statistik Wien as he always patiently delivered me the necessary data.

Last but not least, I want to thank my family and friends who directly and indirectly supported me.

Abstract

Several studies suggest that certain subgroups in society bear a higher environmental noise burden than others. This thesis provides the first analysis on environmental noise pollution and socioeconomic inequalities for the city Vienna, Austria. Hence, the socioeconomic position on the registration district level is assessed by constructing a neighbourhood socioeconomic position index (NSPI) using the population register data by means of Principal Components Analysis (PCA). In addition, a road traffic noise index (RTNI) is constructed from the Lden (day-evening-night) noise indicator by the European Noise Directive (END) using geographical information system (GIS) tools. The RTNI is used to identify areas affected by road traffic noise pollution i.e. areas where the threshold of 55 dB is exceeded according to the World Health Organisation (WHO).

A linear dependency between the NSPI and the RTNI was tested by the Pearson correlation coefficient. Furthermore, the Boolean overlays were computed to identify the distribution of double burden/blessing with respect to the neighbourhood socioeconomic position and road traffic noise pollution. The results indicate a citywide weak correlation between the NSPI and the RTNI and an uneven distribution of a double burden/blessing: there are twice as many neighbourhoods with a high socioeconomic position and a low noise pollution than neighbourhoods with a low socioeconomic position and a high noise pollution.

It is recommended to increase public awareness as well as fostering scientific research and strategic political interventions such that access to a healthy and secure environment does not become an economic privilege in Vienna and Austria.

Zusammenfassung

Mehrere Studien weisen darauf hin, dass Umweltbelastungen sozial ungleich verteilt sind. Die vorliegende Diplomarbeit untersucht für Wien den Zusammenhang zwischen Straßenverkehrslärmverschmutzung und räumlicher, sozioökonomischer Ungleichheit. Mit den Daten des Wiener Bevölkerungsregisters wurde mit Hilfe der Principal Components Analysis (PCA) ein soziökonomischer Nachbarschaftsindex (NPSI) erstellt, um die sozioökonomische Position der Zählbezirke in Wien zu ermitteln. Darüber hinaus wurde ein Straßenverkehrslärmindex (RTNI) mit dem Lärmindex Lden (Tag-Abend-Nacht) der europäische Lärmrichtlinie (END) und mit Hilfe von Geoinformationssystem(GIS)-Werkzeugen erstellt, um den Anteil von straßenverkehrslärmverschmutzen Flächen in den Zählbezirken, die den Richtwert der World Health Organisation (WHO) von 55 dB überschreiten, zu berechnen.

Eine lineare Abhängigkeit zwischen NSPI und RTNI wurde mittels Pearson Korrelationskoeffizienten getestet. Mit Booleschen Operatoren wurde zudem die Verteilung einer Doppelbelastung/-begünstigung zwischen der sozioökonomischen Position und der Straßenverkehrslärmbelastung in den Zählbezirken ermittelt. Für Wien wurde eine schwache Korrelation zwischen NSPI und RTNI sowie eine ungleiche Verteilung der Doppelbelastung/-begünstigung gefunden: es gibt doppelt so viele Zählbezirke mit einer hohen sozioökonomischen Position und einer geringen Lärmbelastung als Zählbezirke mit einer niedrigen sozioökonomischen Position und hoher Lärmbelastung.

Als Handlungsempfehlungen werden öffentliche Bewusstseinsbildung, wissenschaftliche Forschung und strategische politische Interventionen angeführt, damit der Zugang zu einer gesunden und sicheren Umwelt sich nicht zu einem ökonomischen Privileg in Wien und Österreich entwickelt.

Table of Contents

List of Figures

List of Figures in Appendix

List of Tables

List of Tables in Appendix:

List of Abbreviations

BMLFUW	Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management
dB	decibel
EA	Environmental Agency (United Kingdom)
EAP	Environment Action Programme
EC	European Commission
EEA	European Environment Agency
EPA	Environmental Protection Agency (United States)
END	European Noise Directive
EU	European Union
FA	Factor Analysis
FoE	Friends of Earth
FoES	Friends of Earth Scotland
GIS	Geographical information system
KMO	Kaiser-Meyer-Olkin Criterion
Lden	day-evening-night noise indicator
Lnigt	night-time noise indicator
NSPI	Neighbourhood socioeconomic positon index
OECD	Organisation for Economic Co-operation and Development
PCA	Principal Components Analysis
$PM_{2.5}$	Particular matter (2.5 micrometers)
RD	Registration district
RTNI	Road traffic noise index
UK	United Kingdom
UNEP	United Nations Environment Programme
WHO	World Health Organisation

1 Introduction

Environmental justice is based on the idea that environmental advantages and disadvantages should be equitably distributed. Nonetheless studies show that poor people or ethnic minorities suffer disproportionately from a low environmental quality. From an economic perspective an uneven distribution may be legitimate due to the 'natural' forces of supply and demand in a marked-based economy. But from an environmental justice perspective it is considered as unjust that certain subgroups in society bear a higher burden of environmental disadvantages. It is argued that all people regardless of race, colour, national origin, income or education should have an equitable access to a healthy and secure environment.

Environmental noise pollution is the second worst environmental cause of illness after air pollution. Road traffic is the most widespread source of environmental noise. 125 million people are affected by noise levels greater than the recommended World Health Organisation (WHO) guideline value of 55 decibel (dB) Lden (day-evening-night) within the European Union (WHO, 1999b; EEA, 2014). Thus, noise pollution is increasingly being recognised as a public and environmental health problem. Furthermore, several studies suggest, that the noise burden is unequally distributed within society. Köckler et al. (2008); Mielck et al. (2009); Lam and Chung (2012) demonstrated that the noise burden is higher in poorer districts and for residents of low socioeconomic position in Munich, Kassel and Hong Kong, whereas studies from Bocquier et al. (2013); Méline et al. (2013) recorded the highest potential of residential exposure to road traffic noise in mid-level deprived areas and in advantaged neighbourhoods in Marseille and Paris.

For Austrian cities there are no studies available that link environmental pollution with social conditions of the neighbourhoods. However, due to recent findings in the environmental justice research it can be assumed that in Austrian cities an uneven distribution of environmental burdens such as road traffic noise pollution may exist.

Therefore, I examine in my thesis the socio-spatial distribution of road traffic noise within an environmental justice framework for Vienna, capital of Austria. The analysis is concerned with the distributional dimension of environmental justice. The objective is to examine the spatial distribution of road traffic noise pollution and to identify the spatial distribution of socioeconomic characteristics including the ethnic composition of the neighbourhoods in Vienna. The road traffic noise indicator Lden derived from strategic noise maps according to the European Noise Directive (END) is analysed with geographical information system (GIS) tools to construct a road traffic noise index (RTNI) describing the areal noise pollution equal or higher than the WHO recommended guideline value of 55 dB Lden at the registration district level. Socioeconomic data derived by the Viennese population register are used to construct a neighbourhood socioeconomic position index (NSPI) at the registration district level using Principal Components Analysis (PCA). The final step of the analysis is to explore the relationship between these two distributions, for example: are there neighbourhoods with a low socioeconomic position and a high level of road traffic noise pollution (double burden) and are there neighbourhoods with a high socioeconomic position and a low road traffic noise pollution (double blessing), is there an uneven distribution of the double burden/blessing? The hypothesis of my thesis is: ‘the higher the level of road traffic noise pollution in a neighbourhood is, the lower is the socioeconomic position of the neighbourhood’ which is tested using Pearson correlation coefficient.

In the first section of my thesis I give a brief insight into the field of environmental justice and the determining theories and approaches for capturing the socioeconomic position concept. Furthermore I present an overview of environmental noise and recent findings in the environmental justice research of environmental noise. That is followed by the section ‘material and methods’ in which the creation of the RTNI and the NSPI and their test for association is described. Results are presented in maps and discussed in the last section.

2 Background

2.1 Environmental justice

2.1.1 Origins of environmental justice

Scholars refer to the protests back in 1982 in the United States, when civil rights activists and residents demonstrated against the building of a toxic waste landfill in Warren County, North Carolina - the country with the highest proportion of African Americans, as the beginnings of the environmental justice movement (Mohai et al., 2009; Laurent, 2011). Environmental justice is closely linked to the manifestation of ‘environmental racism’ – racial and ethnic inequalities in the exposure to environmental risk (as e.g. pollution, toxic waste) and the exclusion of racial minorities (especially African Americans, Hispanics and native Americans) from the definition and implementation of environmental policies (Laurent, 2011).

As the protest movement gained media attention and raised public awareness about environmental concerns of African Americans and other people of colour in the United States (Bullard, 2000; Roberts & Toffolon-Weiss, 2001; Pellow & Brulle, 2005), investigations and researches addressing the issue started to emerge. The first ground breaking national study was published in 1987 by the United Church of Christ: “*Toxic Wastes and Race in the United States*” (Commission for Racial Justice, 1987). The study verified the unequal and discriminatory siting of toxic waste facilities across the United States and concluded that race is the most important factor in predicting where these waste sites are located. The book “*Dumping in Dixis*” (Bullard, 2000) published by the sociologist Bullard in 1990 is the first major study of environmental racism that links hazardous facility siting with historical patterns of spatial segregation in the southern United States.

The topic of environmental justice expanded in academic circles. The conference on “*Race and the Incidence of Environmental Hazards*” at University of Michigan in 1990 brought researchers from the United States together to study the racial and socioeconomic disparities in the distribution of environmental contaminants. The proceedings of the conference were forwarded to the Environmental Protection Agency (EPA) (Mohai et al., 2009) and in response the EPA installed the ‘Environmental Equity Workgroup’ for further investigation into the issue (Laurent, 2011). In 1992, the EPA published the report “*Environmental Equity: Reducing risk in all communities*” (EPA, 1992) that supported earlier findings and resulted in the installation of the Office of Environmental Equity which became the Office of Environmental Justice in 1994.

The high peak of the environmental justice movement is reached on February 11, 1994, with Executive Order 12898 "*Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*" (EPA, 2015a). By this order, the Clinton administration transformed a civic cause into a federal obligation. All federal agencies have to integrate the objective of environmental justice as part of their mission (Laurent, 2011) and all are directed to identify and address the disproportionately high and adverse human health or environmental effects of their actions on minority and low-income populations (EPA, 2015a).

Warren County became symbolic for a new social movement as the middle-class white environmentalists failed to include this kind of issue: people of colour and poor communities are facing environmental/ecological risks greater than they do (Mohai et al., 2009). Johnson (2012) states that the environmental justice movement is motivated by very different concerns, attracts different people and defines differently the constitution of the environment. While environmentalism defines environment as the untainted nature and is about protecting pristine wilderness, environmental justice is an anthropocentric movement for civil rights and social justice in an urban context that defines environment where people live, work and play (Johnson, 2012).

Furthermore, Johnson (2012) argues that the members of traditional environmental organizations are generally from the financially secure middle and upper classes, who do not rely on employment in environmentally exploitative or polluting industries and who have leisure time to spend enjoying nature, whereas environmental justice is a grassroots and community-based movement of the vulnerable and disenfranchised. Similarly Mohai et al. (2009) argue that the mainstream environmental movement ignored social justice and quality issues and still does so, as there is no consensus among environmentalists that including justice is a good idea. Bullard et al. (2008) argue that the environmental justice movement redefines what environmentalism is all about.

2.1.2 Definition of environmental justice in the United States

Due to the institutional developments, environmental justice is today a vigorous and fully legally operational notion in the United States and the United States is the most advanced country in recognizing the need to address environmental inequalities (Laurent, 2011). The EPA presents today a clear definition of environmental justice:

"*Environmental Justice is the fair treatment and meaningful involvement of all people regardless of race, colour, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. EPA has this goal for all communities and persons across this Nation. It will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work*" (EPA, 2015b, p. 1).

This definition addresses with 'fair treatment' and 'meaningful involvement' two dimensions of justice and distinguishes between distributional and procedural justice (Laurent, 2011). The idea behind environmental justice is that environmental advantages and disadvantages should be equitably distributed. But equitable distribution does not imply a completely even or equal distribution where everybody receives the exact same share of burdens and benefits. Environmental justice is based on the idea that all people should have access to a healthy and secure environment in which to live, work and play and that no one, irrespective of race, culture, geographic location, or socioeconomic position should be exposed to unnecessary or preventable hazards (Johnson, 2012).

However recognition of the principle of environmental justice by federal agencies and various institutional implementations does not imply that environmental inequalities have been removed or that environmental justice has been achieved in the United States (Beretta, 2012). Bullard et al. (2008) conclude in the updated report "*Toxic Waste and Race at Twenty: Why race still matters after all of these years*" that people of colour are found to be more concentrated around hazardous waste facilitates than the first report in 1987 showed and significant racial and socioeconomic disparities today still exist despite societal attention to the problem.

Many empirical studies show a valid link between racial and socioeconomic status and an unequal distribution of environmental conditions (Pastor, 2007; Bullard et al., 2008). There is still an ongoing academic debate on the relative weight of socioeconomic class versus race in environmental injustice claims as the question has still not been answered - which factor comes first? Mohai (2008) argue that to understand environmental inequality, it is necessary to understand which role both race and class play as disparities can be found along both dimensions. Studies show that racial disparities persist when socioeconomic factors are controlled and other studies show that socioeconomic disparities persist when race is controlled (Mohai et al., 2009). As Laurent (2011) states, it is problematic to break up social and racial factors in environmental inequality research and this argument also leads to the European perspective on environmental justice and inequalities.

2.1.3 Environmental justice in Europe

As Finger and Zorzi (2013) point out, the environmental justice debate in the European Union (EU) is much younger than in the United States and the European debate focuses on the social reasons for environmental injustice and not only on the racial dimension. The discussion within the institutions of the European Union is especially driven by the development of the 1998 Aarhus Convention that provides access to information on environmental status, public participation in environmental decision making and access to justice in environmental matters (Schwarte & Adebowale, 2007; Laurent, 2011). The convention is implemented by two directives on the access to environmental information, public participations in environmental decision making and access to justice in environmental matters (Directive 2003/4/EC and Directive 2003/35/EC) that are enacted by the European Parliament and Council in 2003.

Friends of the Earth (FoE), an established and mainstream environmental group, started researching with an environmental justice frame in the early 2000's that proximately reflects the United States model of analysing the distribution of polluting industries. But in contrast to the United States model, the research focused on siting in relation to patterns of income and not on patterns of race or ethnicity (FoE, 2001). Due to the promotion work by Friends of the Earth of Scotland (FoES), a version of the concept of environmental justice was used in a speech of Jack McConnell, Scotland's first Minister, in 2002 who explicitly refers to 'environmental justice' as a policy objective. Prime Minister Tony Blair followed in 2003 with a speech also arguing that environmental burdens are carried by those with poor quality of life and raising environmental standards would have the greatest impact on the poorest areas (EA, 2007; Slater & Pedersen, 2009; Walker, 2009). Laurent (2011) considers these two speeches as integration of environmental justice concerns into social policy in Europe. Furthermore, the United Kingdom (UK) is seen as the first EU member state addressing environmental justice, as it adopted the national sustainable development strategy, "*Securing the Future*" in 2005, putting emphasis on addressing environmental injustice (Finger & Zorzi, 2013). The UK is also seen to be the only state contributing to the debate on the distributive dimensions of environmental justice within the European Union, as the two directives implemented under the European law are only addressing the procedural dimension of environmental justice (Schwarte & Adebowale, 2007).

2.1.4 Definition and adoption of the environmental justice framework in Europe

In a report published in 2007, the UK Environmental Agency (EA) identifies and defines the following elements, among others, as parts of environmental justice:

- "*Distributive justice is concerned with how environmental 'goods' (e.g. access to green space) and environmental 'bads' (e.g. pollution and risk) are distributed amongst different groups and the fairness or equity of this distribution.*
- *Procedural justice is concerned with the fairness or equity of access to environmental decision-making processes and to rights and recourse in environmental law.*
- *Policy justice is concerned with the principles and outcomes of environmental policy decisions and how these have impacts on different social groups*" (EA, 2007, p. 8).

France and Germany entered the discussion later. Although there is evidence that in France polluting sites are disproportionally located near minorities' communities, the French government has not put environmental justice on the agenda (Viel et al., 2011). Germany in contrast focuses the discussion on public health. The information service Environment and Human Health, a contribution to the German Action Programme Environment and Health (APUG – German NEHAP), published in 2011 a special issue on environmental justice with emphasis on health (UMID, 2011). Sweden played a major role in the discussion and development of sustainability internationally, yet environmental justice does not play a role within the state (Finger & Zorzi, 2013).

Although the environmental justice concept has reached Europe, there are major differences in the development, conception and definition of the environmental justice idea. The initial meaning is derived from the United States context, but it is not simply reproduced or abandoned (Agyeman & Evans, 2004). As the geography of environmental justice matters, it has to be defined within the context for each site in which it is used and it cannot be readily universalised under only one conceptualisation (Debbané & Keil, 2004; G. Williams & Mawdsley, 2006).

The distributional and procedural aspects are distinguished in both cases, but Europeans highlight the social conditions producing injustices while Americans focus on the racial dimension producing discrimination and exclusion from decision-making process that ethnic groups suffer (Laurent, 2011). Pastor (2007) argues environmental justice issues are not likely to be perceived, analysed and framed in racial and ethnic terms in Europe but in terms of social categories. In the United States environmental justice is born in a broader civil rights movement and was thus 'racialized' from the beginning. Due to differences in the cultural and legal background of public policy in the United States and the European Union, racial minorities are recognized as groups by the United States federal law and not low-income communities. Thus, race can be a basis for legal action in courts, while income level cannot be. However, it is criticised that the adoption of the environmental justice frame by 'elites' in existing established environmental groups and government agencies in the European Union weakens the substance and significance of the environmental justice frame in comparison to the United States version (Walker, 2009).

2.1.5 Market-based cause of environmental injustice

Beck (1992) argues that environmental problems are fundamentally based in how human society is organised. To understand origins of environmental inequalities it is therefore necessary to imbed environmental injustice in the social dynamics that produce inequality and environmental degradation. In literature, the underlying mechanism of the market economy within society is referred to as one of the key dynamics that systematically create environmental inequality (Brulle & Pellow, 2006).

Economy-based analyses of environmental injustice are in literature referred to as market-based or market-dynamic explanation for environmental injustice (Ringquist, 2002). The market-based explanation for environmental inequality is grounded in neoclassical economics (Earle, 1996). The fundamental assumption in neoclassic economics is the self-interested, atomistic, rational entity that is reflected in any form such as an individual, a household, a firm or a public institution. The rational entity weights benefits against costs under economic calculus such as maximising the utility and profit. The rational firm wants to lower production and transaction costs when doing business and the rational individual want to maximise utility using available resources under a budget constraint. The public institution strives for two goals: to increase revenues via taxes on e.g. labour and capital and to maintain the public health and environmental integrity. In addition, government and industry strive for the path of least resistance when siting a polluting facility or undesirable land uses. They consider public opposition as negative because these could generate controversies about siting or a delay in construction plans which causes higher costs (Bullard & Wright, 1987; R. W. Williams, 1999; Cole & Foster, 2001).

Based on that assumption it is rational for industry and a public institution to place facilities and undesirable land uses where land is cheap and where industrial labour pools and sources of materials are nearby. Communities that are most capable of creating an effective opposition are also avoided. This may coincide with locations where already poor people and ethnic minorities live. As communities with political influence and abundant resources tend to be white, affluent and well connected, the location where a new facility or undesirable land use is sited may also be a place where a disproportionately high number of poor people and ethnic minorities live (Mohai et al., 2009). In addition, after a new facility/undesirable land use is placed in the neighbourhood the ethnical and socioeconomic composition may change. The new facility/undesirable land use may introduce negative impacts on the quality of life of neighbours such as noise, higher levels of traffic or pollution of water bodies. As it is rational for an individual or household to live where utility is maximized with respect to its budget constraint, some neighbours may dislike living close to the new facility/undesirable land use and individuals and households more affluent will move away leaving poorer residents behind. As ethnic minorities are likely found within lower income groups the proportion of these people is increasing in the neighbourhood of the new facility (Mohai et al., 2009).

The logic of the neoclassic economic market dictates that facilities/undesirable land use with negative external effects will tend to decrease land value. As the new facility/undesirable land use brought negative impacts into the neighbourhood, property values decline and housing rents become more affordable for those with low income. Thus, individuals and households less affluent become attracted to the neighbourhood moving in and increasing the concentration of poor people around the facility (R. W. Williams, 1999). Within the market-based explanation it is argued, that the economic benefits due to decreased unemployment and cheaper housing that brings industry and undesirable land use predominates the costs of living and working in a polluted and hazardous neighbourhood for the utility maximising individuals and households (Johnson, 2012).

Following this argumentation, industry or public institutions are not intentionally discriminating against ethnical minorities or the poor; they are simply acting as a rational entity. It is rational for a firm to seek the lowest cost of business, it is rational for the public institution to attract industry and operate community facilities as well as avoid public opposition and it is also rational for an individual to live in a neighbourhood that increase utility. Consequently unevenly distributed environmental burdens originate from the underlying ‘natural’ mechanism of the supply and demand in a given neighbourhood. Thus, the market dynamics within the neoclassic economic framework provide a most likely cause of a disproportionately higher number of low-income people and ethnic minorities around noxious facilities or undesirable land uses (R. W. Williams, 1999; Mohai et al., 2009).

2.1.6 Criticism of the market-based explanation of environmental injustice

The market-based explanation for origins of environmental inequalities delivers an inherent consistent, logical and neutral argumentation, but it has to be seen critically. It clearly underpins the powerful hegemonic ideas of the neoclassic economic market system as cost effectiveness and maximising utility become the main criteria by which the distribution of environmental burdens are assessed (Okereke, 2006). By justifying an uneven distribution of environmental burdens with economic forces, economic interests of individuals, public institutions and industry beat concerns about health and well-being. Advocates of the market-based explanation counter therefore, that negative external effects and arising injustice can be even out through financial or other forms of compensation (Johnson, 2012).

Although the utilitarian paradigm underlying the neoclassic economic system brings the possibility of compensation, the concept of compensation has to be seen critically too. Opponents of compensation schemes argue that it is immoral to pay those who are less affluent to accept the risks others can afford to escape. It is argued, that is immoral to commodify certain matters as life, health and safety or human dignity and compensation should not be applied when issues of basic needs are at stake. In addition, compensation schemes take unfair advantage of an existing unequal distribution of wealth (Been, 1992) where people with access to economic means can easily change their situation as e.g. move away from polluting industry. Therefore compensation schemes are sometime labelled as 'environmental blackmailing', as direct payments or compensation via e.g. employment are forcing less affluent people to make a choice between economic and environmental well-being (Johnson, 2012).

Compensation schemes are not only seen critically from an ethical point of view but also from a pragmatic point of view. Costs, benefits and risks of facilities or other undesired land uses need to be translated into monetary terms. Techniques like hedonic pricing and the contingent valuation method are applied for measuring the value of risks and harms of environmental problematic facilities and undesired land uses. But these techniques are still not able to fully assess the costs of environmental threats. This is especially true for facilities as nuclear power plants that pose risks for hundreds or thousands years (Been, 1992).

Opponents of the market-based explanation criticise furthermore that in the capitalist society economic discrimination is considered as legitimate. Although it is unfair to discriminate against people on the basis of characteristics as e.g. race or gender which they cannot change, it is not unfair to treat people differently if they are e.g. poor or less affluent as these attributes are not an intrinsic element of their identity and therefore can be changed. But it is also cruel to assume, that poor people just simply change their circumstances by mere effort that reduce economic disadvantage (Johnson, 2012).

2.1.7 A fair and equitable distribution of environmental benefits and burdens

The idea behind environmental justice is that environmental benefits and burdens should be equitably distributed. However, an equitable distribution is not considered as an entirely even or equal distribution where all people are treated in the same way or receive the same share of environmental advantages or disadvantages. Some groups such as the poor might have a greater need for certain resources and services such as public transport so that granting a greater access to these goods can be justified (Johnson, 2012).

Indeed, there is no clear definition in literature or in governmental documents how exactly a fair distribution of environmental benefits and burdens has to look like. Been (1992) also argues, that as long as the notion ‘fair’ is not linked to a specific theory of fairness, it is impossible to determine what a fair distribution of environmental burdens and benefit is.

In general, the debate over definitions of ’fairness’ or ‘justice’ has not ended yet, as still scholars, politicians and citizens define these notions differently depending on their values and beliefs. This can not only be observed in the discussions within the environmental justice framework but also in discussions about e.g. the distribution of wealth (Been, 1992).

In addition, the Universal Declaration of Human Rights does not ensure the basic human right on environmental health. Although some basic human rights imply the function of the environment such as the right to clean water, an explicit human right on a healthy environment cannot be found (humanrights, 2015). Indeed, in recent years proponents of environmental justice have extended the principle of basic human rights into the sphere of the environment. They argue that increasing scarcity of and conflict over natural resources needs new approaches for securing a peaceful future (Taylor, 2004).

The United Nations Environment Programme (UNEP) also recognizes the environment as a pre-requisite for the enjoyment of human rights and due to the rise of the environmental justice framework, the UNEP is nowadays debating about an approach that implements the right to a safe, healthy and ecologically-balanced environment as a human right itself (Taylor, 2004; UNEP, 2015).

2.2 Capturing socioeconomic conditions in society

As mentioned in the previous section, the analysis of environmental justice in Europe focuses on the links between environmental burdens and socioeconomic conditions. In general there are numerous ways to characterise and define social and economic conditions. Concepts like social class, social stratification, social or socioeconomic status/position are used to determine the influencing factors of the social and economic composition of society. Most of these concepts have their origin in the work of two social theorists, Karl Marx and Max Weber (Lynch & Kaplan, 2000; Hradil, 2012).

Marxian theory defines society as stratified into 'classes' that are determined by the nature of exploitative production relations. Marx constitutes 'class' in the relationship between groups who own the means of production (factories, financial institutions, etc.) and those who do not. The class relations and social class are described by the inherent conflict between the exploiting owners that control the means of production and the exploited workers (Lynch & Kaplan, 2000; Galobardes et al., 2007).

Weberian theory defines society as stratified in multiple ways (by class, status, political power, etc.) that creates groups with an unequal distribution of economic resources, skills and life possibilities. The class position is not primarily determined by the relations in production but by the free-market opportunities generated by these productive relations. These generate different sets of skills, knowledge and assets - in the Weberian terminology the so called 'life chances' of the individuals. Therefore the individuals can improve their market situation and life chances by bargaining or obtaining more skills and knowledge. The most commonly used indicators for the measurement of socioeconomic conditions, such as education, occupation and income, are based on Weber's ideas of social stratification (Lynch & Kaplan, 2000).

Both theories can be used to describe a framework of unequal distribution and control over resources that could result in a social patterning in the exposure to environmental burdens. Socioeconomic conditions are not only created on an individual level - they are also determined by structural relations between groups within a society. For instance, the level of education reached by an individual is restricted to the available educational opportunities in a society and also by the family background (Galobardes et al., 2007).

There are a number of practical approaches to conceptualise and measure the socioeconomic conditions as there is no single-best indicator representing socioeconomic position (Salmond & Crampton, 2002). Most studies in that field use the multiple dimensions of social stratification to describe and measure socioeconomic position. Most frequently quoted domains are: education, income, wealth, housing, overcrowding, occupation, ethnicity, race, employment/unemployment, family characteristics and poverty rates (Nancy Krieger et al., 2003; Dall, 2006; Messer et al., 2006; Galobardes et al., 2007; Diekmann & Meyer, 2010; Krishnan, 2010; Nega et al., 2013).

2.2.1 Individual socioeconomic position

To determine the socioeconomic position of an individual these domains are combined. Individuals with similar attributes are grouped together which results in a stratification of the society. The top and the bottom of the social stratification are defined by society. In modern society a high level in education, occupational status, a steady job and wealth are associate with a high position in society, whereas a low level in education, unemployment, immigration status and material poverty are associated with a low position in society (Salmond & Crampton, 2002; Dall, 2006).

The socioeconomic position of the individual has a lot of consequences, as in Weberian terms the socioeconomic position determines the life chances of the individual. It is argued that groups with certain resources or living conditions have always better chances in realising their lives. For example, individuals with a high position in society are thinking more optimistic and are more performance-oriented and future-oriented. In addition, they are less often sick, are living longer, have a better social network and their children have better educational opportunities (Hradil, 2012).

Therefore inequalities of opportunities exist in particular between: educational and occupational groups, households with and without children, residents of different regions, gender, ages and ethnic groups. These are also the most important determinants that create social inequality. Some of them are individually acquired such as level of education, occupational status, and family status which can be more or less freely chosen - depending on the family background - by the individuals. Whereas other determinants are socially attributed such as gender, age, social background or ethnicity that cannot be changed by the individual. Inequalities of opportunities that are based on these determinants, for example discrimination against women or ethnic minorities, are considered in modern societies as illegitimate (Hradil, 2012).

2.2.2 Neighbourhood socioeconomic position

The socioeconomic position can be evaluated not only at the individual level but also at the neighbourhood level. Especially in the absence of individual socioeconomic data, area-based socioeconomic measures are increasingly recognized. These area-based indicators can be conceptualised as meaningful indicators standing by themselves and providing information on area-level characteristics not reducible to the individual level e.g. concentration of poverty and environmental attributes (N. Krieger et al., 2003). Area-level indicators of socioeconomic position are gained by the aggregation of individual level measures as e.g. unemployment rates, proportion with higher education, etc. and are aggregated to the area-level of question e.g. census tract, district, state or country (Galobardes et al., 2007).

Area measures can also be used to assess ‘contextual’ socioeconomic effects which means that the area measure represents an important aspect of exposure to certain socioeconomic and environmental conditions (Haan et al., 1987; G. D. Smith & Dorling, 1996). In other words, the percentage of unemployment in a neighbourhood not only indicates something about the individuals who live there (the composition of the neighbourhood); it may also provide other information about the neighbourhood that determines the risk of exposure to environmental pollution of all those who live in the neighbourhood and not just the unemployed individuals. Therefore, the neighbourhood characteristics may have a contextual effect on the individual exposure to environmental pollution (Lynch & Kaplan, 2000).

Especially in the field of environmental justice, by its nature, area-based indicators are often used to analyse the socio-spatial distribution of environmental burdens.

2.3 Environmental noise

According to the WHO, environmental noise, also referred to as noise pollution, is the most common environmental complaint in Europe, especially in urban areas and residential areas close to traffic infrastructure (WHO, 2011). Noise pollution is becoming a growing environmental concern. It has been recognised as a quality of life and well-being issue. Adverse effects can be found on the well-being of exposed populations and in the high economic price society has to pay due to noise pollution (EEA, 2014, 2015). There is sufficient evidence from epidemiological studies linking the exposure to environmental noise with adverse health effects. Therefore noise pollution is increasingly being recognised as a public and environmental health problem (WHO, 2011; EEA, 2015).

The European Environment Agency (EEA) defines environmental noise according to the European Noise Directive (END) as follows:

"Environmental noise shall mean unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity [….]" (EU, 2002, p. 2).

The EEA report "*Noise in Europe*" stated that road traffic is the most widespread source of environmental noise with an estimated 125 million people affected by noise levels greater than 55 dB Lden, including more than 37 million exposed to noise levels above 65 dB Lden (EEA, 2014).

2.3.1 Health effects and economic costs

Direct and indirect adverse health impacts can be linked to the burden of persistent or high levels of noise. Stress reactions, sleep-stage changes and other biological and biophysical effects can occur due to the exposure to increased noise levels. Furthermore these could lead to the impairment of various health risk factors such as high blood pressure or in the development of clinical symptoms like insomnia and cardiovascular diseases and finally increase the rate of premature mortality (EEA, 2014).

Thus, the guideline values are set by the WHO as follows:

– for an outdoor living area at 55 dB LAeq (LAeq for daytime = 16 hours)

– outside bedrooms at 45 dB LAeq (LAeq for night-time = 8 hours)

These guideline values represent the sound pressure levels that have a critical health effect on the receiver (WHO, 1999b).

The WHO describes the severity of health effects due to noise compared to the number of people affected with the pyramid as Figure 1 shows. A high number of people are affected by slight health effects due to noise as annoyance, disturbance or other stress indicators as autonomous response whereas a low number of people are affected by severe health effects as sleep disturbances and mortality caused by noise.

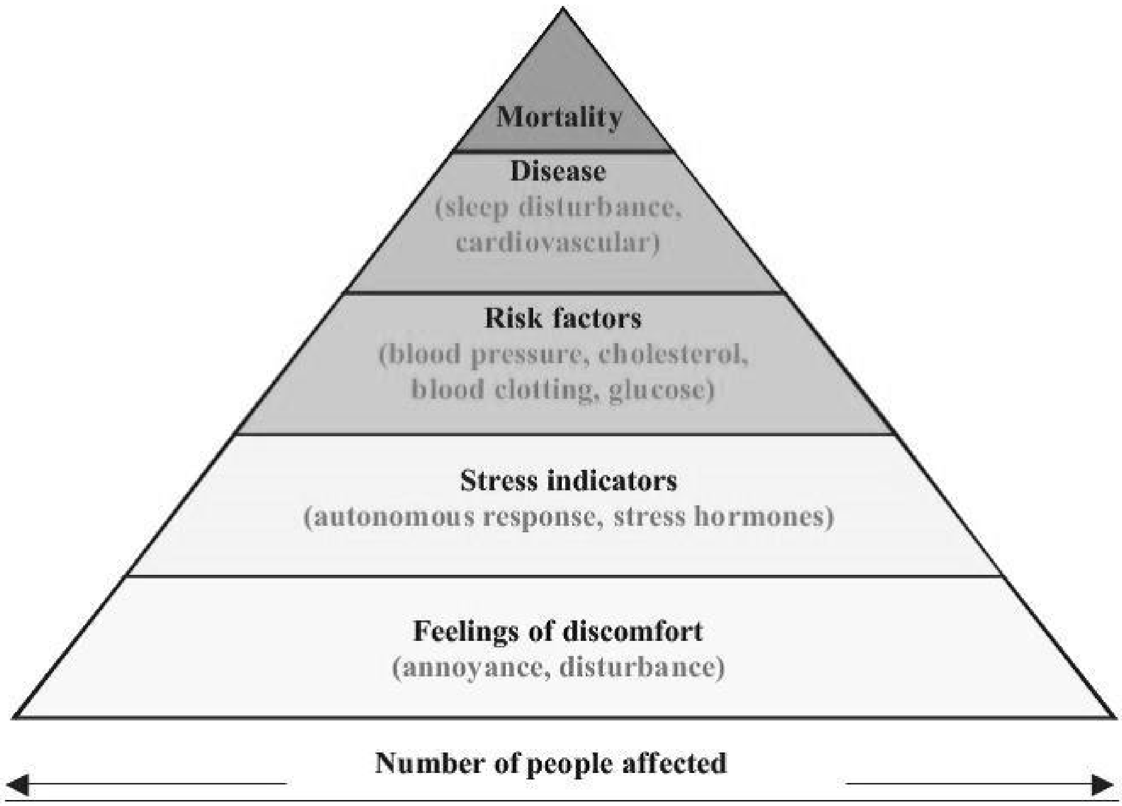


Figure 1: Severity of health effects of noise and number of people affected (WHO, 2011, p. 100)

The WHO pyramid is also in accordance with the findings of the EEA: almost 20 million adults are annoyed by noise pollution, and a further 8 million are affected by sleep disturbances. Over 900 000 cases of hypertension are caused by environmental noise each year. Noise pollution causes 43 000 hospital admissions in Europe and at least 10 000 cases of premature death in Europe each year (EEA, 2014).

The European Commission (EC) considers social costs of noise pollution as the reduction of house prices, reduced possibilities of land use, increased medical costs and the cost of lost productivity in the workplace due to illness caused by the health effects of noise pollution

(EC, 1996). Boer and Schroten (2007) estimate the social costs of road traffic noise within the EU to be at least € 38 billion per year which is about 0.4% of the total GDP. The authors remark that the estimation only reflects effects related to noise levels above 55 dB Lden whereas people might already be adversely affected by noise below this level. Therefore the estimation of social costs is probably underestimating the actual costs.

2.3.2 Regulations of environmental noise

In the 6th Environment Action Programme (EAP) "*Environment 2010: Our Future, Our Choice*" covering the period 2002-2012, the EU aspired "*to achieve an environmental quality that does not significantly impact or risk human health*" (EU, 2001, p. 7). At that time the EC already pursued protection against noise as stated in the "*Green paper on Future Noise Policy*" (EC, 1996), since the EU institutions recognized the past and future developments of noise pollution, the magnitude of the exposed population and linked health effects. Therefore the 6th EAP was followed by the adoption and implementation of a directive on environmental noise – the "*Environmental Noise Directive*"(END) in 2002 (EEA, 2014).

The aim of the END is to define a common approach to avoid, prevent or reduce the harmful effects, including annoyance, due to exposure to environmental noise. It should also provide the basis for measures to reduce noise emitted by major sources, especially road and rail vehicles and infrastructure, aircraft, outdoor and industrial equipment and mobile machinery (EU, 2002).

The END also defines common noise indicators to address both annoyance and sleep disturbance. These indicators represent the description of environmental noise that is associated with harmful effects. Two indicators are:

– the Lden – the day-evening-night-level indicator designed to assess annoyance

– the Lnight – the night-level indicator designed to assess sleep disturbances.

The END requires the member states, on the basis of these indicators, to produce strategic noise maps for all major roads, railways, airports and agglomerations. The 7th EPA defines 'high noise levels' as noise levels above 55 dB Lden and 50 dB Lnight (EU, 2013). Therefore these indicators have to be applied to noise mapping exposure assessments beginning at 55 dB for Lden and at 50 dB for Lnight. These strategic maps must satisfy minimum requirements that are listed in Annex IV of the END. The information on environmental noise based on the strategic noise maps and the maps itself have also to be made available to the public (EU, 2002; EEA, 2014).

2.3.3 Environmental noise in Vienna

Two sources are available to determine the current state of environmental noise in Vienna. Statistic Austria collects data on environmental quality and behaviour in the micro census. In 2011 the micro census also collects for the first time data on the most important environmental problems. The results of the census show that most of the respondents are concerned about the increased traffic volume and consider this should have the highest priority in managing environmental problems. The results for Vienna show that 58.4% of the population is annoyed by environmental noise, 52.1% of the population is annoyed by traffic noise in general, whereas 43.2% of the population is annoyed by road traffic noise in particular (Statistik Austria, 2013).

The END is implemented into national law by the law “Bundes-Umgebungslärmschutzgesetzt” and this is complemented by state legislation. Strategic noise maps are already available for Vienna for the year 2007 and 2012 (BMLFUW, 2015). Although the methodology for the strategic noise maps is completely different, the results of the strategic noise maps for Vienna in 2012 are similar. Around 46% of the population is exposed to noise levels equal or higher than 55 dB Lden (BMLFUW, 2015).

Nonetheless, these results for Vienna are not set in an environmental justice context. The results show only a spatial dimension as the exposed population is linked to the district level. With the available data, only the ratio of exposed to total population on the district level can be shown. But these results do not show any social nor ethnic components - noise exposure may be an additional burden in potentially vulnerable subgroups such as lower socioeconomic groups or ethnic minorities.

2.4 Environmental justice and environmental noise – recent findings

Noise is characterised as the second-worst environmental cause of ill health, after $PM_{2.5}$ air pollution (EEA, 2014). The 7th Environmental Action Plan of the EU acknowledges this fact with the objective of decreasing noise pollution in the EU significantly towards the WHO recommended levels by 2020 (EEA, 2014). Noise, especially noise caused by road traffic, is not only a major issue in health studies but also in environmental justice research.

In terms of environmental justice, recent studies examine the socio-spatial distribution of road traffic noise. Contrary to the common perception, the results show a heterogeneous picture. Bocquier et al. (2013) recorded the highest potential of residential exposure to road traffic noise in mid-level deprivation areas in Marseilles, France. Havard et al. (2011) found that people living in advantaged neighbourhoods of Paris, France are likely to be more exposed to road traffic noise in their residential environment than their deprived counterparts. Brainard et al. (2004) concluded that there is no relationship between noise exposure and population age as well as a weak evidence of an association between noise exposure and ethnicity and weak disparities in noise exposure and levels of socio-economic deprivation in Birmingham, UK. Tobias Lakes and Brückner (2011) found no systematic citywide environmental injustice in noise in Berlin, Germany, however there are areas that carry double burden in terms of high noise levels and low social status and of areas with low noise levels and high social status. Köckler et al. (2008); Mielck et al. (2009); Lam and Chung (2012); Nega et al. (2013) in turn demonstrated that the noise burden is higher in poorer districts and for residents of lower socioeconomic status in Munich, Germany, Kassel, Germany, Minnesota, US, and Hong Kong. In a Europe-wide study by the WHO, the majority of the 30 reporting countries identify a higher self-reported noise exposure at home among individuals living in relatively poverty (WHO, 2012).

Most et al. (2004) explain that heterogeneity of the findings by the dependency of environmental justice research on spatial scale. They conclude that findings in environmental justice research change if the spatial scale of the research design is changed.

In Austria, environmental justice research is underdeveloped. There is only one study that explores the social aspects of climate change impacts. Prettenthaler et al. (2008) concluded that Austrian people experiencing poverty contribute less to climate change and suffer by a higher proportion than wealthy Austrian people from the consequences of climate change.

3 Material and Methods

3.1 Study area

The socio-spatial distribution of road traffic noise is analysed for Vienna, the capital of Austria. The total area is 41487 ha, where 45.5% of the area is classified as green space, 35.6% as building zones, 14.3% as traffic zones and 4.6% as water bodies (MA 23, 2015b). Green Space can be found especially in suburban areas and along the Danube River, whereas traffic zones can be found predominantly in inner-city areas and also in the south-eastern part of Vienna (see Figure 2).

Vienna has 23 political districts, 250 registrations districts and 1364 census districts (Stadt Wien, 2015b). The unit of analysis in the thesis is the registration district (RD) which stands for a neighbourhood in Vienna. RDs are statistical units that combine one or more census districts that have a similar structure and function for which socioeconomic and demographic information is available (Statistik Austria, 2015b).

The number of RDs is not equally assigned to the districts; the area is also not the same for each RD. The biggest RDs can be found at the periphery of Vienna which have also a high proportion of green space; smaller RDs can be found in the inner-city of Vienna which have high portions of building zones and traffic zones (see Figure 2). The smallest RD has an area of 16.50 ha whereas the biggest RD has an area of 2608 ha.

In 2011 around 1.7 Million people were living in Vienna (MA 23, 2015a). The Viennese population is not equally distributed over the RDs. There is one RD with only two people living in it and one RD with 25208 people living in it (Stand 2011). More than half of the RDs have a population between 3000 and 11000 citizens.

Densely populated RDs can be found in inner city areas whereas sparsely populated RDs can be found in the suburban areas and also in the city centre of Vienna. The densest populated RD is located on the south east edge of Vienna, surrounded by sparsely populated RDs (see Figure 3). A listing of all RDs and associated population numbers and areas can be found in the Appendix.

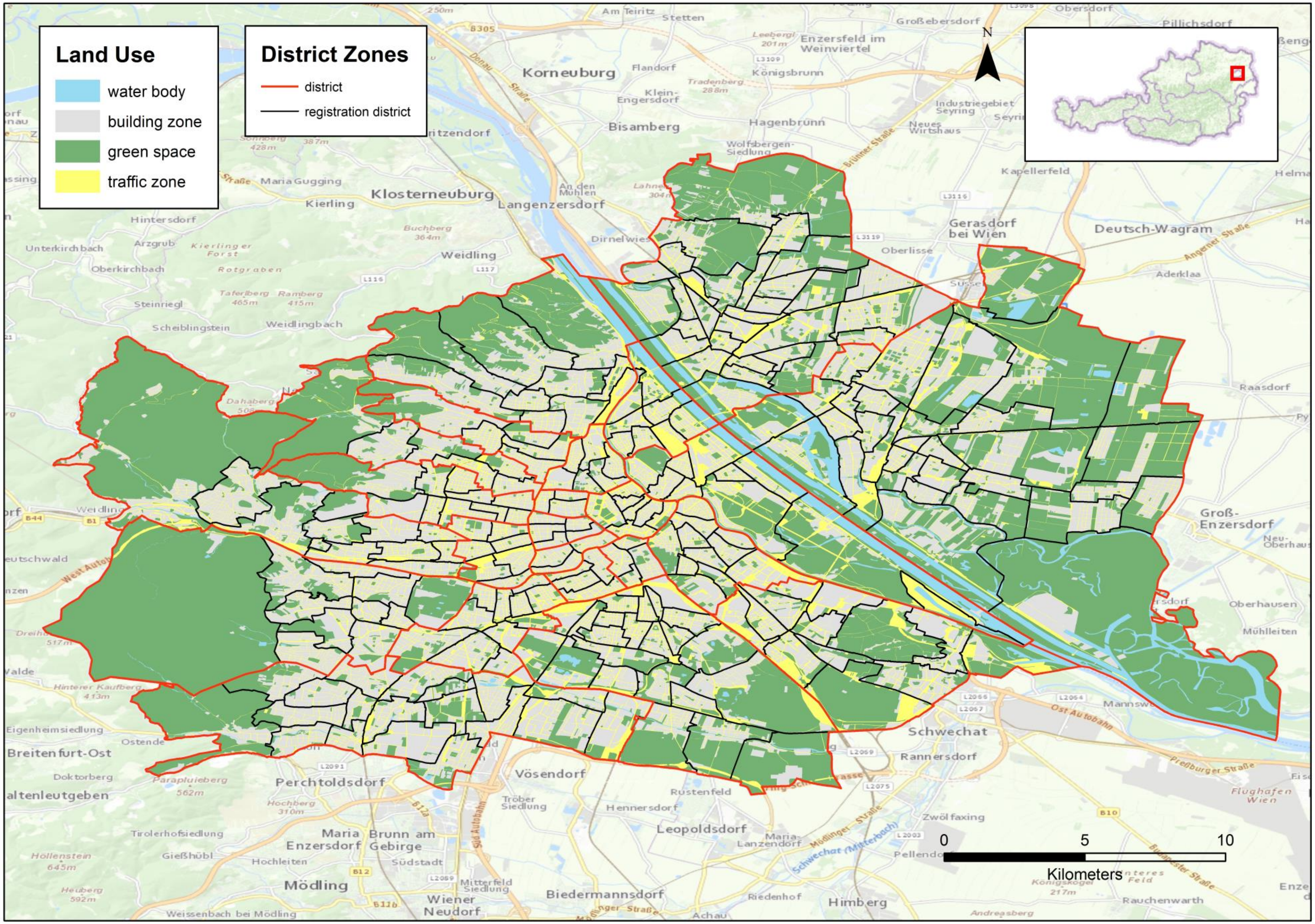


Figure 2: Distribution of land use zones and districts zones over Vienna (Stadt Wien, 2015a)

Figure 3: Population density in Vienna, stand 2011 (MA 23, 2015a)

3.2 Data

Socioeconomic data on the RD level were received from the Municipal Department 23 – Economic Affairs, Labour and Statistics of the Viennese government. This data were derived from the Viennese population register, reference date 31.10.2011 and were available as count data (MA 23, 2015a).

Road traffic noise data were received by the website www.laerminfo.at hosted by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW). The BMLFUW provides on the webpage the strategic noise maps in accordance with the END. The street noise maps for Vienna show the street traffic noise using the noise indicators Lden and Lnight in dB (BMLFUW, 2015). The data as presented on the webpage www.lärminfo.at are shown in Figure 4.

Data source for RD boundaries was the website open.wien.gv.at hosted by the government of Vienna (Stadt Wien, 2015a).

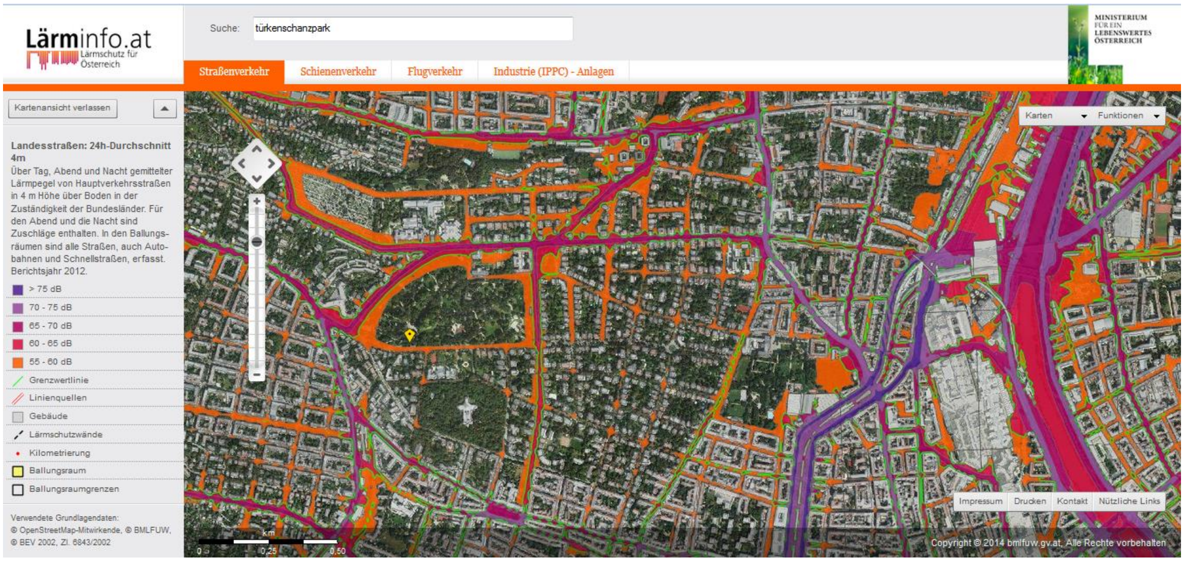


Figure 4: Section of the web-based map of road traffic noise pollution in Vienna for 2012 (BMLFUW, 2015)

3.3 Methods

3.3.1 Neighbourhood socioeconomic position index - NSPI

For ssessing the socioeconomic position of the RDs, I created a neighbourhood socioeconomic position index (NSPI). As mentioned before, there are various dimensions that contribute to the socioeconomic position and there is no 'best' single indicator representing the socioeconomic position. The calculations for the NSPI were done with R-Project for Statistical Computing with the package FactoMineR, developed by Le et al. (2008).

For constructing composite indices there are various different methodologies available. Within multivariate analysis the Organisation for Economic Co-operation and Development (OECD) suggests the following methods for constructing an index: Principal Component Analysis, Factor Analysis, Cronbach Coefficient Alpha and Cluster Analysis (OECD, 2008). The approach most often used for creation of socioeconomic indices is beside Factor

Analysis (FA) the Principal Components Analysis (PCA). FA and PCA are both data reduction techniques commonly used in neighbourhood level analysis to create socioeconomic scales or indices (Messer et al., 2006; Vyas & Kumaranayake, 2006). For creating the NSPI I decided to apply the PCA as the major strength of the PCA is the summarisation of a set of induvial indicators while preserving the maximum possible proportion of the total variation in the original data set (OECD, 2008).

The PCA creates from an initial set of correlated variables uncorrelated components, where each component is a linear weighted combination of the initial variables (Vyas & Kumaranayake, 2006). The uncorrelated principal components are a useful characteristic of the PCA methodology as they reveal and measure different statistical dimensions in the data. Therefore a huge data set can be presented in using a few variables, the principal components, so that the data are reduced from a complex, multidimensional frame to a single dimension which is easier to interpret (Manly, 2004; OECD, 2008; EC, 2013). The linear combination that explains the maximum amount of variation is called the' first principal component'. A second principal component independent of the first component is then found explaining as much as possible of the remaining variability. Further components are then created sequentially, each new component being independent of the previous one (Abeyasekera, 2003). The weights for each principal component are given by the eigenvectors of the correlation matrix, or if the original data are standardised by the eigenvectors of the co-variance matrix. The variance for each principal component is given by the eigenvalue of the corresponding eigenvector. The eigenvalues associated with each component represent the inertia of the variance explained (Husson et al., 2010). The sum of the eigenvalues equals the number of variables in the initial data set (Vyas & Kumaranayake, 2006).

When using PCA for constructing a socioeconomic position index, PCA is done several times to filter the most strongly correlated and most contributing variables to the first component. One 'stopping rule' is the so called 'Kaiser-criterion' suggesting that components with an eigenvalue greater than one can be selected for further analysis (OECD, 2008). As a result, a first component is found that can be used to represent the socioeconomic position as a linear combination of several variables most contributing to the socioeconomic position (Dall, 2006; Havard et al., 2008). Mathematics of the PCA methodology can be found in literature as in e.g. Husson et al. (2010), OECD (2008), L. I. Smith (2002) and Vyas and Kumaranayake (2006).

Figure 5 describes the several steps in creating the NSPI for Vienna. To define the neighbourhood socioeconomic position I started with a literature review. A description of the underlying theories and concepts of socioeconomic position can be found in the section 2.2.

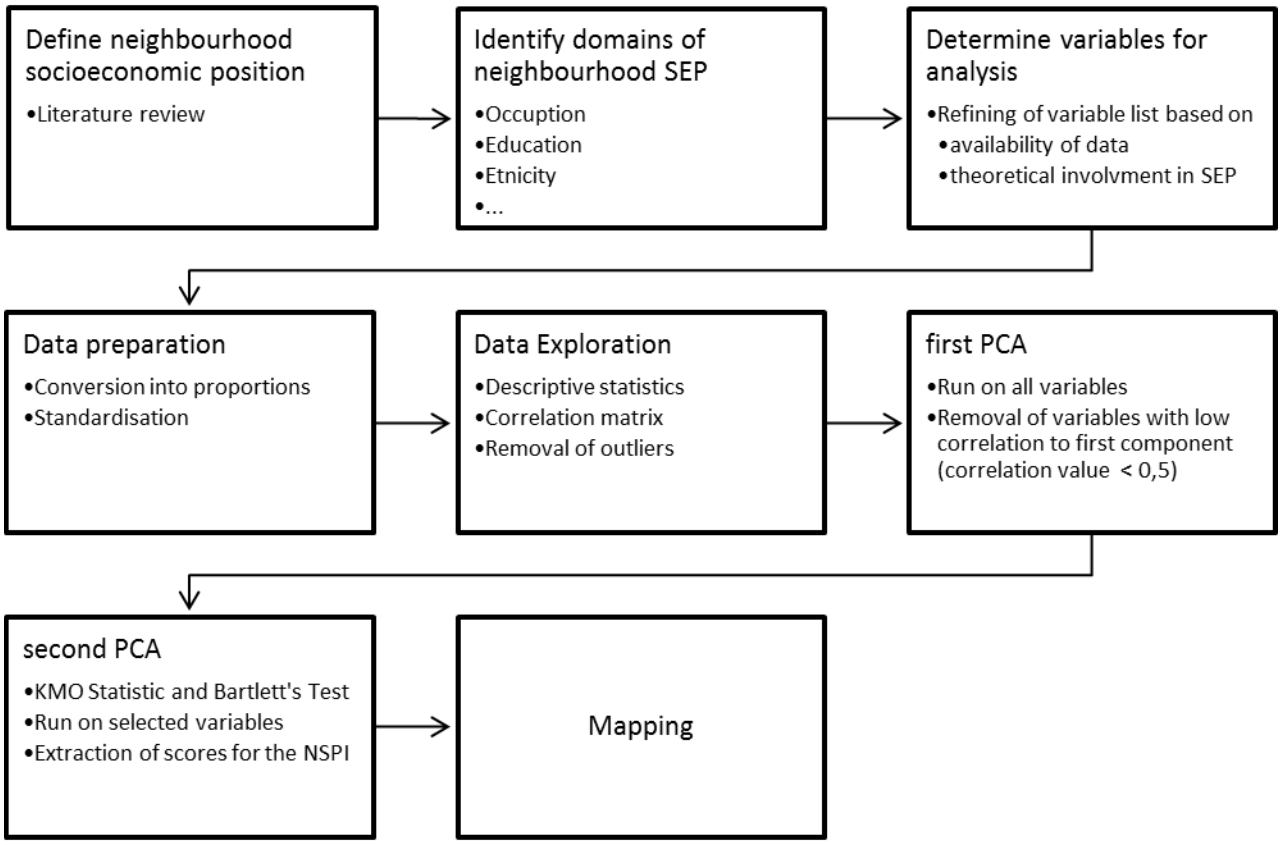


Figure 5: NSPI model

Based on the literature review I identified most often used domains in constructing neighbourhood socioeconomic position as follows: education, occupation, demography, income, housing, wealth, overcrowding, ethnicity, family composition, mobility, poverty and governmental support. An overview of selected papers and a summary of the used domains in creating an area-based socioeconomic position index are given by Table 1.

Table 1: Domains used in creating an area-based socioeconomic position index - Overview

Domain	**Author**
Educational Level, Occupational Level, Unemployment or Disability, Severe Financial Problems	Bosma et al. (2001)
Income, Labour Force, Education, Demography, Housing	Dall (2006)
Education, Income, Wealth, Occupation-Based Indicators, Unemployment, Housing, Overcrowding	Galobardes et al. (2007)
Employment, Family and Household, Educational Level, Housing, Immigration Status, Income	Havard et al. (2008)

Education, Income, Occupation, Unemployment, Poverty, Parenthood, Housing, Overcrowding, Racial/Ethnic Composition	Krishnan (2010)
Family and Household, Immigration and Mobility, Employment and Income, Education, Housing	Lalloue et al. (2013)
Education, Employment, Housing, Occupation, Poverty, Racial Composition, Residential Stability	Messer et al. (2006)
Income, Employment, Communication, Transport, Governmental Support, Qualifications, Housing	Salmond and Crampton (2002)

In the next step, I determined the variables to describe the several domains of the socioeconomic position concept based on data availability and theoretical involvement in the socioeconomic position concept. That resulted in 34 variables which describe the domains age, sex, occupation, education, ethnicity, housing and family composition which can be found in in Table 2. In addition the operational definition of the variables for the PCA and their indication for a low or high socioeconomic position according to the literature review are also given. Variables to describe the domains income, mobility, poverty, or governmental support were not used, as data on the RD level were not available (MA 23, 2015a; Statistik Austria, 2015a).

For preparing the data for exploration and for the PCA I converted all data into proportions on the RD level. Furthermore, to do the PCA I had to standardise the variables, which means that the data were scaled to unit variance. This was essential as the variables had not the same base unit e.g. the number of owner-occupied units was divided by the total amount of units whereas the number of unemployed people was divided by the number of people in the labour force.

Table 2: Variables used for the creation of the NSPI (RD level)

Domain	Variable Used	Operational Definition (given in proportions)	Indication low/high SEP
Age	0 – 24 years	People younger than 25 years in the total population	-
	25 – 64 years	People between 25 and 64 years in the total population	-
	65+ years	People older than 64 years in the total population	-
Sex	Male	Male people in the total population	high
	Female	Female people in the total population	low
Occupation	Blue-collar workers	Blue-collar workers in the labour force*	low
	White-collar workers	White-collar workers in the labour force*	high
	Civil servant	Civil servants in the labour force*	high

	Self-employed	Self-employed in the labour force*	high
	Unemployed	Unemployed in the labour force*	low
Education	Compulsory school	People with compulsory school graduation (highest level) in 15 years old and more population	low
	Apprenticeship	People with apprenticeship graduation (highest level) in 15 years old and more population	low
	Lower and upper secondary school	People with intermediate general or vocational maturity certificates (highest level) in 15 years old and more population	high
	College	People with college graduation (highest level) in 15 years old and more population	high
	University	People with university graduation (highest level) in 15 years old and more population	high
Ethnicity	Austria	Austrian citizens in the total population	high
	Serbia / Montenegro	Serbian/Montenegrin citizens in the total population	low
	Turkey	Turkish citizens in the total population	low
	Germany	German citizens in the total population	low
	Poland	Polish citizens in the total population	low
	Bosnia	Bosnian citizen in the total population	low
	Croatia	Croatian citizen in the total population	low
	Romania	Romanian citizen in the total population	low
	Czech Republic	Czech citizen in the total population	low
	Hungary	Hungarian citizen in the total population	low
	Others	Other citizen in the total population	low
Housing	Owner-occupied units	Owner-occupied units of total units	high
	Non-owner occupied units	Non-owner occupied units of total units	low
	Overcrowding	Less than 1 room per person and per unit	low
	Number of persons per unit	1 person per unit	high
		2 persons per unit	high
		3 to 5 persons per unit	low
		6 and more persons per unit	low
Family Composition	Lone parenthood	Single-parent families in the total population	low

*Labour force: people between 15 to 64 years old

For data exploration I created descriptive statistics and a correlation matrix. The descriptive statistics showed various extreme minimum and maximum values which is due to the different population number of the RDs. In addition, I detected RD 210 with a total population of two citizens as outlier so I decided to remove that RD from further analyses. As the descriptive statistics of the 249 RDs showed a lot zero values for the different ethnicities I created a further variable for all non-Austrian citizens on the RD level. The descriptive statistics with the remaining 249 RDs and with the new variable non-Austrians can be found in Table 3. The correlation matrix (see Appendix) already showed positive/negative correlation coefficients >= 0.5 within the domains education, occupation, ethnicity and housing.

Table 3: Descriptive statistics without outlier (RD level)

Variable	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
X0.24	7.69	23.26	25.61	25.69	28.06	38.58
X25.64	45.25	54.18	56.74	56.97	59.49	86.67
X65.	0.00	13.67	16.47	17.34	21.55	32.29
bluecollar	3.19	12.44	18.58	19.45	26.38	45.46
whitecollar	9.71	29.79	35.41	34.54	39.45	52.39
civilservant	0.97	6.95	8.94	9.65	11.67	31.58
selfemployed	0.00	5.20	6.88	8.13	10.11	25.28
unemployed	0.00	0.28	0.49	0.56	0.77	4.85
compulsory	3.01	8.78	12.66	13.90	19.04	34.41
apprenticeship	4.27	11.74	16.85	16.97	21.22	41.67
secondary	9.32	17.73	19.58	20.04	21.83	33.90
college	0.00	0.51	0.65	0.67	0.84	1.58
uni	0.00	8.67	12.36	14.81	21.45	35.87
owner	0.27	11.44	17.56	24.13	29.98	90.24
nonowner	0.00	64.28	76.66	70.01	83.43	98.45
male	43.10	46.84	47.86	48.23	48.90	69.23
female	30.77	51.10	52.14	51.77	53.16	56.90
loneparenthood	0.00	4.75	5.23	5.17	5.64	7.27
X1perunit	20.52	39.36	45.83	43.65	48.68	80.00
X2perunit	0.00	27.52	29.28	29.74	31.73	43.07
X3.5perunit	9.84	21.09	23.44	24.98	27.33	49.23
X6.perunit	0.00	1.13	1.51	1.63	1.95	7.48
overcrowding	0.00	5.27	6.96	8.09	10.46	37.81
austria	46.15	74.72	81.96	80.61	88.75	97.87
serbiamontenegro	0.00	1.32	2.50	3.38	4.78	12.85
Turkey	0.00	0.56	1.37	1.98	2.92	9.59
germany	0.00	0.99	1.48	1.88	2.56	5.95
poland	0.00	0.72	1.24	1.51	1.85	23.08

bosnia	0.00	0.32	0.70	0.93	1.30	6.67
croatia	0.00	0.39	0.71	0.85	1.16	4.90
romania	0.00	0.38	0.69	0.84	1.05	7.69
czechrepublic	0.00	0.10	0.16	0.17	0.21	0.75
hungary	0.00	0.31	0.47	0.50	0.65	2.80
others	1.19	4.24	6.90	7.37	9.62	27.23
nonAustrians	2.13	11.25	18.04	19.39	25.28	53.85

The first PCA was done with all variables without the outlier RD to find the variables contributing (correlation coefficient >= 0.5) most to the first component and to reveal a possible structure in the variability of the data. For a better interpretation of the results of the first PCA, I calculated the correlation coefficients between the variables and the components with an eigenvalue > 1 (Kaiser criterion). That gave me a table with the correlation coefficient and the p-value of the variables which were significantly correlated to the principal components (variables with p-value < 0.05). For the second PCA variables with a correlation coefficient >= 0.5 to the first component were selected. Although the variables 'male' and 'female' had a correlation coefficient >= 0.5, they were not included in the second PCA. There is no clear interpretation in the influence of gender on the neighbourhood socioeconomic status as they had the same absolute correlation coefficient. The variable '2 persons per unit', was also not taken into account for the second PCA. It had a lower correlation coefficient than overcrowding, and housing can be represented by the variable overcrowding as well. Due to the revealed structure by the second principal component, a variable representing the domain ethnicity which includes all non-Austrian and non-German citizens was created for the second PCA.

Based on the results of the first PCA, the variables compulsory school, blue-collar workers, non-Austrians and non-Germans, unemployed, civil servants, college, Austrians, secondary school and white-collar workers were selected for the second PCA. In addition, I made a Kaiser-Meyer-Olkin (KMO) Statistic[1] and Bartlett's Test[2] on the selected variables to ensure the appropriateness of the remaining variables for the creation of NSPI. The second PCA

[1] The concept behind the KMO Statistic is that the partial correlations should not be very large if distinct components are expected to emerge from PCA. The KMO statistic compares the magnitudes of the observed correlation coefficients to the magnitudes of the partial correlation coefficient. It is computed for each individual indicator and their sum is the KMO overall statistic. KMO varies from 0 to 1. A KMO overall should be 0.60 or higher to proceed with PCA, a value of 0.90 is considered as 'marvellous', 0.80 as 'meritorious', 0.70 as 'middling'(OECD, 2008; Krishnan, 2010).

[2] The Bartlett's Test of Sphericity tests the strength of the relationship among the variables. It tests the null hypothesis if the variables in the population correlation matrix are uncorrelated (OECD, 2008; Krishnan, 2010).

resulted in a first component that explains most of the variability in the data and also fulfils the Kaiser-Criterion. Hence, I extracted the scores of the first component for each RD which represented the neighbourhood socioeconomic position of each RD. A full list with the scores of all RDs can be found in the Appendix. In the final step the scores were classified in deciles and mapped.

3.3.2 Road traffic noise index - RTNI

The END specifies that the noise indicators Lden and Lnight have to be applied as a method to describe environmental noise and especially road traffic noise (EU, 2002). For constructing the RTNI, I used the Lden for the year 2012 as it represents the sound level over 24 hours and not just only for the night hours.

The Lden is a weighted long-term average sound level over all day periods of a year assessed 4 m above the ground (EU, 2002). The Lden is available for all streets in Vienna with road traffic noise levels equal or higher than 55 dB (BMLFUW, 2015). Consequently a road not showing Lden values does not imply that there is no road traffic noise.

State of the art in assessing the spatial distribution of road traffic noise is the application of geographical information system (GIS) tools (Farcaş & Sivertunb, 2005; Ogneva-Himmelberger & Cooperman, 2010; Ko et al., 2011). The Lden values for Vienna were all available as shapefile readily usable for processing in any GIS software package.

For identifying the road traffic noise burden on the RD level I used the GIS tools ‘zonal statistics’ and ‘tabulate intersection’ in ArcGIS 10.2 (Esri, 2012, 2013) as similar done in the study by Tobia Lakes et al. (2014). With zonal statistics it was possible to calculate the mean Lden value for each RD from the affected roads by road traffic noise equal or higher than 55 dB Lden. Furthermore, with the tool tabulate intersection I was able to calculate the percentage of affected area by road traffic noise equal or higher than 55 dB Lden for each RD. The results were classified in deciles and finally mapped. The technical implementation of the data processing for creating the RTNI in ArcGIS 10.2 can be found in the Appendix.

3.3.3 Combining the NSPI and the RTNI

Studies that examine an association between environmental burdens and socioeconomic position use different statistical methods to calculate significant results as e.g. Spearman rank correlation, Moran's Index, OLS regression model, Kolmogorov-Smirnov test, bivariate correlation, Pearson correlation coefficient, binary logistic regression analysis or simultaneous autoregressive model (Brainard et al., 2004; Diekmann & Meyer, 2010; Lam & Chung, 2012; Bocquier et al., 2013; Nega et al., 2013; Tobia Lakes et al., 2014). Furthermore graphical methods as decile analysis or Boolean overlays are used to allow a more differentiated picture of environmental justice (Lam & Chung, 2012; Tobia Lakes et al., 2014).

For proving my hypothesis: 'the higher the level of road traffic noise pollution in a neighbourhood is, the lower is the socioeconomic position of the neighbourhood', I tested for association between the NSPI and the RTNI using the Pearson correlation coefficient[3]. Furthermore the second PCA was done with the supplementary variable '% affected area by noise >= 55 dB Lden (area.noise)' to determine if the RTNI is correlated with the variables of a low neighbourhood socioeconomic position or with the variables of a high neighbourhood socioeconomic position.

In addition, to answer my research question 'is there an uneven distribution of a double burden/blessing in Vienna?' I classified the NSPI and the RTNI values in deciles and calculated Boolean overlays of the categorised data. Therefore I grouped the lowest 20% (the first two deciles) and the upper 20% (last two deciles) of the RDs, respectively on the NSPI classification scale and on the RTNI classification scale. The first two deciles of the RDs on the RTNI scale were categorised as RDs with a low noise pollution whereas the last two deciles of the RDs on the RTNI scale were categorised as RDs with a high noise pollution. The first two deciles of the RDs on the NSPI scale were categorised as RDs with a high socioeconomic position whereas the last two deciles of the RDs on the NSPI scale were categorised as RDs with a low socioeconomic position. With Boolean overlays I selected the RDs showing a low neighbourhood socioeconomic position and a high noise pollution and vice versa.

[3]The Pearson correlation coefficient, sometimes referred to as Pearson's R, is a measure of the linear correlation between two variables X and Y giving a value between + 1 and -1 inclusive, where 1 is total positive correlation, 0 is no correlation and -1 is total negative correlation (Salkind, 2010).

4 Results

4.1 NSPI

4.1.1 First PCA

The first PCA was done with the goal to reveal a structure in the variability of the data and to identify the variables for the second PCA. The first PCA delivers a first component with a relatively low maximum percentage of variability in the data. The variables factor map of the first PCA (see Figure 6) shows, that the first component explains 32.05% variability (Dim 1) and the second component explains 17.94% of the remaining variability (Dim 2) in the data. The visual interpretation of the variable factor map reveals a correlation of the domains occupation, nationality, housing and education with the first component. The domains occupation, education and housing are also correlated with the second component.

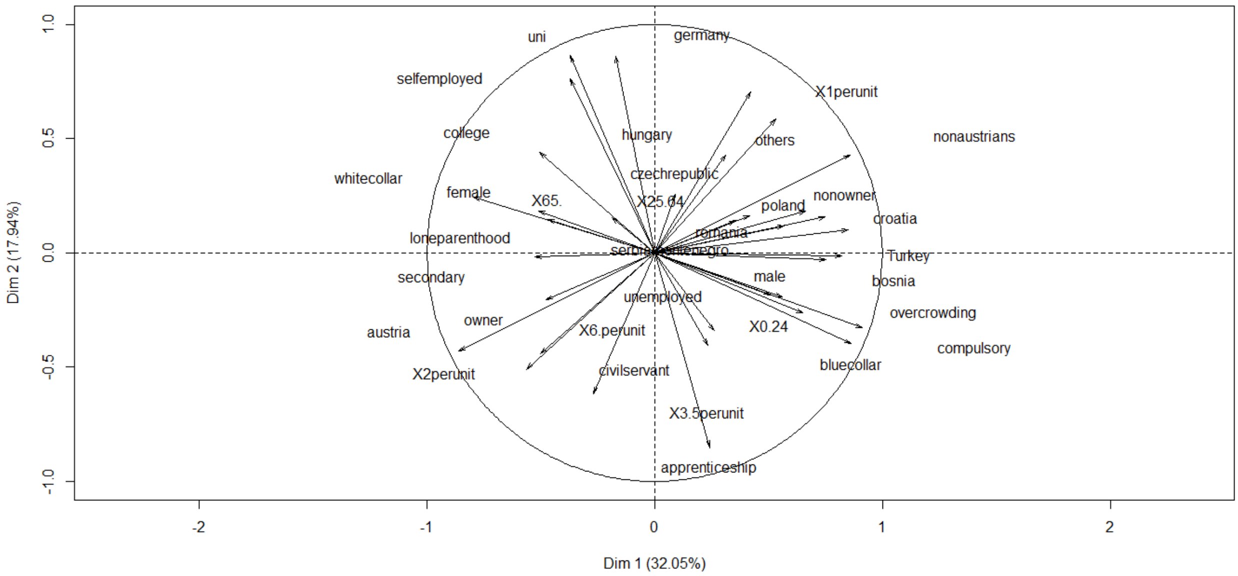


Figure 6: Variables factor map - first PCA

The correlations coefficients between the variables and the first component (eigenvalue > 1) as in Table 4 shown indicate that the first component potentially represents the NSPI concept as described in section 2.2: non-Austrians citizens, low level educated citizens (compulsory) overcrowding and negatively associated occupational status (blue collar and unemployment) are positively correlated with the first component (correlation coefficient >= 0.5) whereas Austrian citizens, high level educated citizens (middle & secondary and college) and positively associated occupational status (white collar and civil servants) are negatively correlated with the first component (correlation coefficient =< -0.5).

The second component also reveals an interesting structure in the remaining variability of the data: highest level educated citizens (university), German citizens and self-employed citizens are positively correlated with the second component (correlation coefficient >0.75). This suggests that the domain ethnicity cannot be interpreted as one single indicator. Furthermore one could argue that it does matter, which ethnicity a person has in relation to the neighbourhood socioeconomic position. In other words, the neighbourhood socioeconomic position in Vienna may be determined by ethnicity. Thus, for the second PCA a variable including the proportions of non-Austrians and non-Germans representing the domain ethnicity is created.

The third and fourth component (eigenvalue > 1) cannot be interpreted in connection with the NSPI nor do they reveal any particular structure in the remaining variability of the data.

Table 4: Correlation coefficients of the variables to the first and second component – first PCA

Component 1			**Component 2**		
Variable	correlation	p.value	variable	correlation	p.value
compulsory	0.91	0.00	uni	0.86	0.00
bluecollar	0.86	0.00	germany	0.86	0.00
nonaustrians	0.86	0.00	selfemployed	0.76	0.00
serbiamontenegro	0.85	0.00	X1perunit	0.71	0.00
Turkey	0.82	0.00	others	0.59	0.00
bosnia	0.75	0.00	college	0.44	0.00
croatia	0.75	0.00	nonaustrians	0.43	0.00
romania	0.66	0.00	hungary	0.43	0.00
overcrowding	0.65	0.00	czechrepublic	0.26	0.00
poland	0.57	0.00	whitecollar	0.24	0.00
unemployed	0.56	0.00	female	0.18	0.00
others	0.53	0.00	romania	0.18	0.00
male	0.51	0.00	nonowner	0.16	0.01
X1perunit	0.42	0.00	croatia	0.16	0.01
nonowner	0.42	0.00	loneparenthood	0.15	0.02
X25.64	0.35	0.00	X65.	0.15	0.02
hungary	0.31	0.00	X25.64	0.14	0.03
X6.perunit	0.26	0.00	male	-0.18	0.00
apprenticeship	0.24	0.00	unemployed	-0.19	0.00
X0.24	0.23	0.00	owner	-0.20	0.00

germany	-0.17	0.01	overcrowding	-0.26	0.00
loneparenthood	-0.19	0.00	compulsory	-0.33	0.00
X3.5perunit	-0.27	0.00	X6.perunit	-0.34	0.00
selfemployed	-0.37	0.00	bluecollar	-0.40	0.00
uni	-0.37	0.00	X0.24	-0.41	0.00
X65.	-0.47	0.00	austria	-0.43	0.00
owner	-0.48	0.00	X2perunit	-0.44	0.00
X2perunit	-0.50	0.00	civilservant	-0.51	0.00
college	-0.50	0.00	X3.5perunit	-0.62	0.00
female	-0.51	0.00	apprenticeship	-0.85	0.00
secondary	-0.53	0.00			
civilservant	-0.56	0.00			
whitecollar	-0.79	0.00			
austria	-0.86	0.00			

The eigenvalue of the first component is greater than one but the first component only explains 32.02% of the variability in the data. That implies that the first component cannot be taken as a single index representing the neighbourhood socioeconomic position. Therefore a second PCA with the variables most contributing to the first principal component (correlation coefficient >= 0.5) was done.

4.1.2 Second PCA

The results of the first PCA leave the following variables for the second PCA: compulsory school, blue-collar worker, overcrowding, unemployed, non-Austrians and non-Germans, Austrians, white-collar worker, civil servant, secondary school and college.

The KMO Statistic shows a value of 0.77, which implies that the data are appropriate for the second PCA and the result of the Bartlett’s Test shows a significance level of zero so the null hypothesis - the variables correlation matrix is uncorrelated - can be rejected (see Table 5).

Table 5: KMO Statistic and Bartlett's Test

Test		Results
KMO Statistic		0.7732186
Bartlett's. Test of Sphericity:	Chi-Square	3473.727
	df	45
	Sig	0.00

The variables factor map of the second PCA (Figure 7) shows a clear picture of the remaining variables: the variables unemployed, compulsory school, overcrowding, blue collar and non-Austrian and non-German citizens are positively correlated with the first component (Dim 1). The variables Austria, civil servant, middle and secondary school and college are also negatively correlated with the first component (Dim 1). The first component explains 59.11% of the variability in the data, whereas the second component explains only 15.67% of the remaining variability in the data. Both components have an eigenvalue > 1.

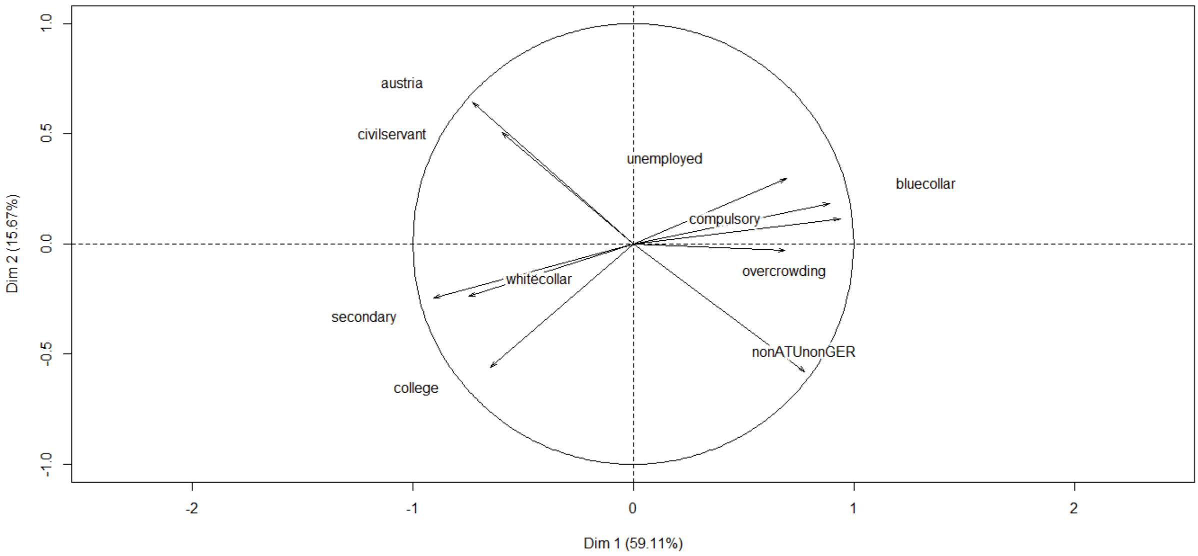


Figure 7: Variables factor map – second PCA

Table 6 shows that each variable has a high correlation with the first component (>= 0.59), which indicates that the first component represents the used variables well. The correlations of the variables with the second component are comparatively low (=< 0.64) and do not give any further explanation of the variability in the data.

Table 6: Correlation coefficients of the variables to the first and second component – second PCA

Component 1	correlation	p.value	Component 2	correlation	p.value
compulsory	0.94	0.00	austria	0.64	0.00
bluecollar	0.89	0.00	civilservant	0.50	0.00
nonAUTnonGER	0.78	0.00	unemployed	0.30	0.00
unemployed	0.69	0.00	bluecollar	0.18	0.00
overcrowding	0.69	0.00	secondary	-0.24	0.00
civilservant	-0.59	0.00	whitecollar	-0.24	0.00
college	-0.65	0.00	college	-0.56	0.00
austria	-0.73	0.00	nonAUTnonGER	-0.58	0.00
secondary	-0.75	0.00			
whitecollar	-0.91	0.00			

The computed results are in accordance with a similar study done by Lalloue et al. (2013) who also created a neighbourhood socioeconomic index. Their PCA for Grand Lyon resulted in a first component explaining 57.99% of the variability and a second component explaining 16.71% variability in the data.

The scores for each RD computed by the PCA are extracted to get the single NSPI values: the RD with the lowest neighbourhood socioeconomic position has a score of 7.016 and the RD with the highest neighbourhood socioeconomic position has a score of -4.357. The median value is -0.466 and the mean value is zero because the data are standardised. The scores are classified in deciles and used for mapping and further analysis.

The map in Figure 8 shows the mapped NSPI scores for each RD classified in deciles. RDs with a low NSPI can be found in the inner-city area, whereas RDs with a high NSPI can be found in the suburban area of Vienna. RDs with a low NSPI are also grouped along the so called ‘Gürtel’, a major road that surrounds the inner-city. RDs with a high NSPI are also located in areas with a high portion of green zones. The map also shows that RDs with lower NSPI and with higher NSPI form agglomerations so that RDs with a similar NSPI are next to each other.

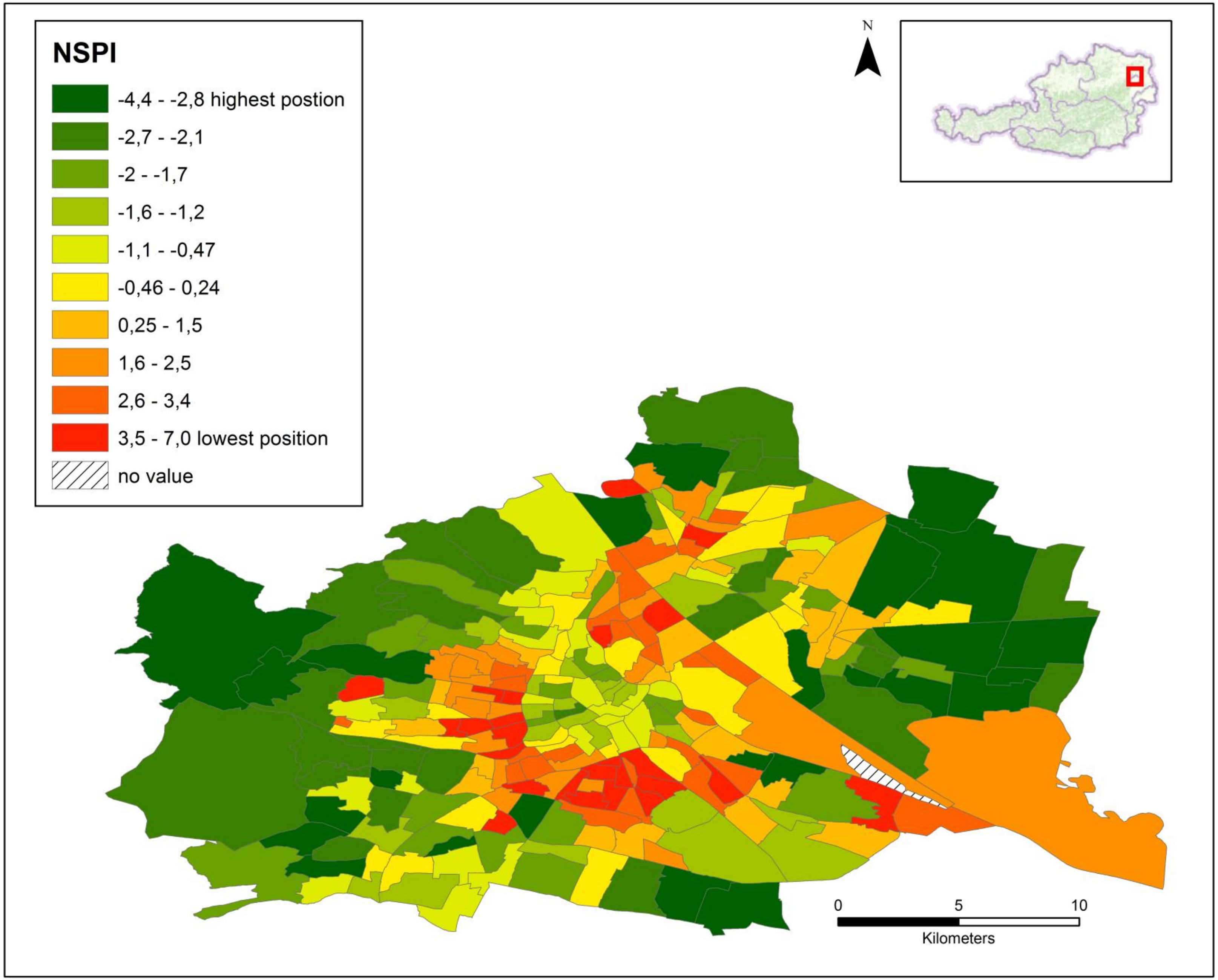


Figure 8: Neighbourhood socioeconomic position index - NSPI (2011)

4.2 RTNI

In general, when looking at the frequency distribution of the road traffic noise affected areas in the RDs as shown in Table 7, a high variation can be determined. Two RDs show no area affected by road traffic noise. As mentioned before this just means that there is no road traffic noise equal or higher than 55 dB Lden. Conversely two RDs show more than 90% of area affected by noise equal or higher than 55 dB Lden. 172 of 250 RDs (68.8%) show a noise affected area between 10% and 50%. In 76 of 250 RDs (30.4%) more than half of the area is affected by road traffic noise.

Table 7: Frequency distribution of noise affected areas (RD level)

% affected area	frequency	cumulative %
0	2	0.80
10	33	14.00
20	57	36.80
30	49	56.40
40	33	69.60
50	22	78.40
60	12	83.20
70	11	87.60
80	12	92.40
90	17	99.20
> 90	2	100.00

Figure 9 shows the RTNI for the different calculation methods and the classification in deciles. The map on the left side shows the mean Lden value of the noise affected areas in each RD ($RTNI_a$). The map on the right side shows the percentage of noise affected area >= 55 dB in each RD ($RTNI_b$).

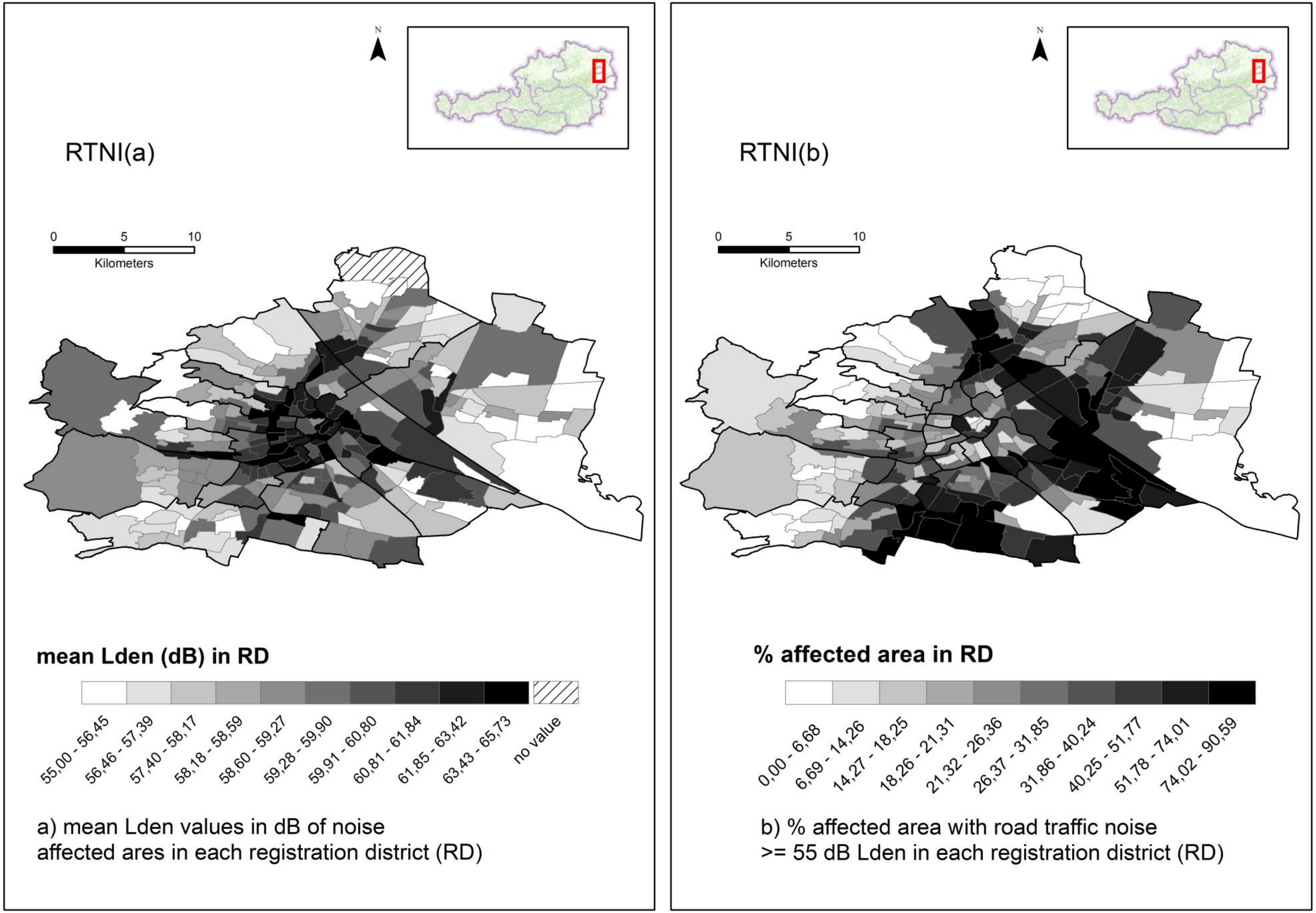


Figure 9: Road traffic noise index – RTNI (2012)

The $RTNI_a$ shows a concentration of road traffic noise in the inner-city RDs. This results from the fact, that in inner-city RDs higher Lden values are more common (see Figure 10).

The $RTNI_b$ shows a concentration of road traffic noise in RDs along the high noise polluted roads. $RTNI_b$ also shows RDs with very low noise pollution and very high noise pollution. The high variation is also resulting from the variation of road traffic noise affected areas over the RDs.

Only two RDs in the northern part of Vienna show lower Lden values than 55 dB so they are classified with the value 0. As mentioned before, this does not imply that there is no road traffic noise, only that the road traffic noise is lower than 55 dB Lden.

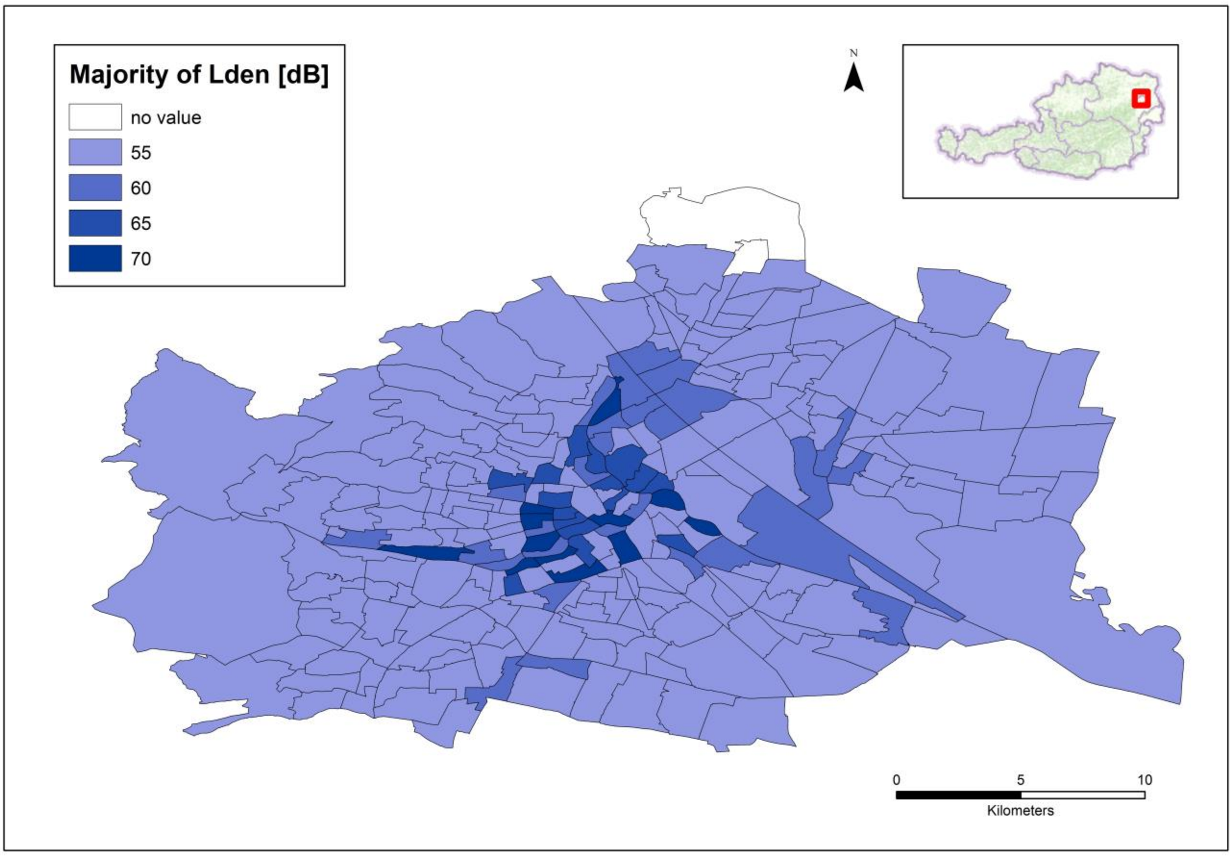


Figure 10: Majority of Lden values in dB (RD level)

4.3 Combining the NSPI and the RTNI

The analysis of the distribution of road traffic noise delivered two results: the mean Lden values in dB on the RD level ($RTNI_a$) and the percentage of area affected by road traffic noise equal or higher than 55 dB ($RTNI_b$) in the RDs. As mentioned in the section 2.3 the WHO guideline value for outdoor noise is 55 dB Lden. Hence, further analysis takes into account the $RTNI_b$ based on the percentage of area affected by road traffic noise.

The test for correlation between the RTNI and the NSPI delivers a Pearson correlation coefficient of 0.15 (p-value = 0.02). Although noise is positively correlated with the variables of a low neighbourhood socioeconomic position (see Table 8), the correlation value is too low to represent a strong linear dependency between the variables of a low neighbourhood socioeconomic positon and the affected area by road traffic noise on the RD level. Therefore the hypothesis 'the higher the level of road traffic noise pollution in a neighbourhood is, the lower is the socioeconomic position of the neighbourhood' must be rejected.

Table 8: Second PCA with '% area.noise' – correlation coefficients to the first component

variable	correlation	p.value
compulsory	0.94	0.00
bluecollar	0.89	0.00
nonAUTnonGER	0.78	0.00
unemployed	0.69	0.00
overcrowding	0.69	0.00
area.noise	0.15	0.02
civilservant	-0.59	0.00
college	-0.65	0.00
austria	-0.73	0.00
secondary	-0.75	0.00
whitecollar	-0.91	0.00

Although there is no strong correlation between the NSPI and the $RTNI_b$ a double burden may still exist. The results of the Boolean overlay are shown in Figure 11. There are 12 RDs (5%) that have a high noise pollution and a low socioeconomic position and there are 24 RDs (10%) with a low noise pollution and a high socioeconomic position. This means that some RDs experience a double burden in terms of high road traffic noise pollution and low socioeconomic position, while other experience a double blessing in terms of low traffic noise pollution and high socioeconomic position.

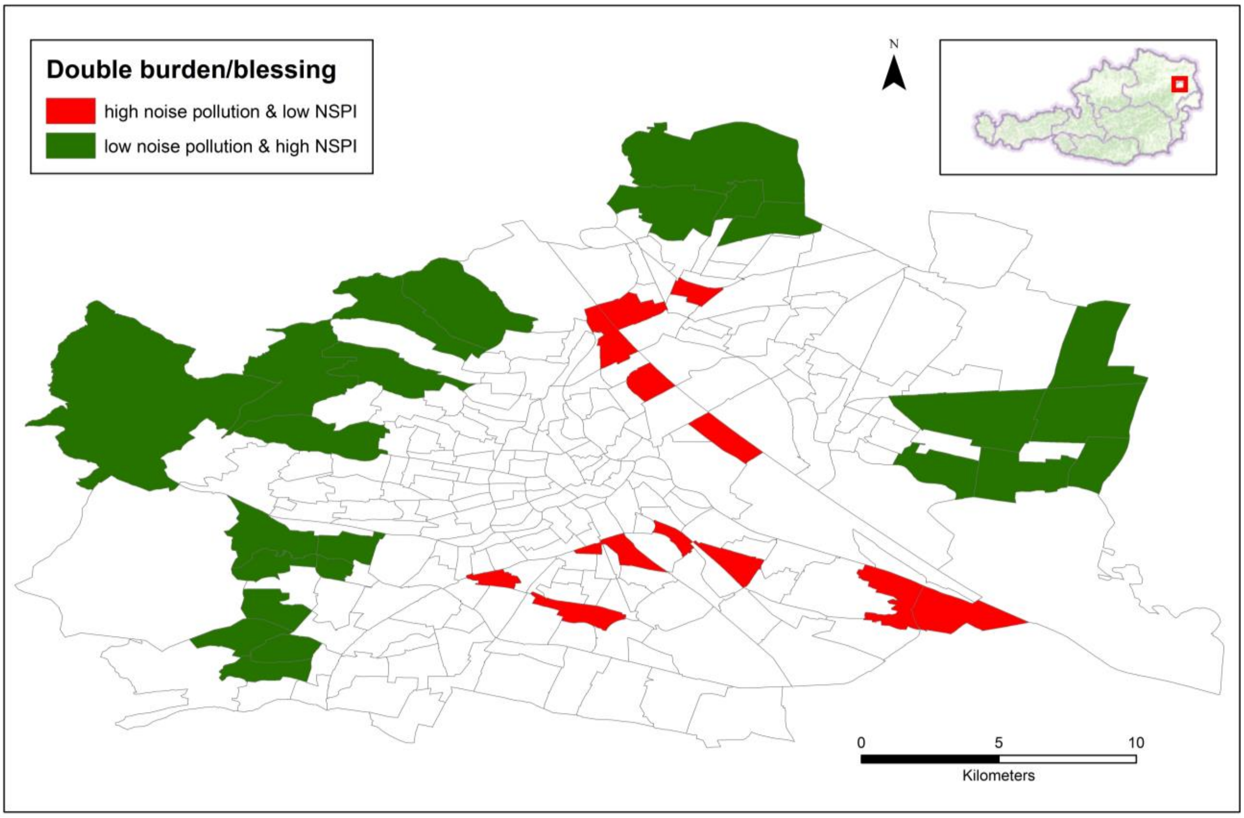


Figure 11: Noise pollution and NSPI in Vienna (2011/12) – double burden/blessing

Furthermore the results reveal an uneven distribution of environmental noise in favour of RDs with a high socioeconomic position. There are twice as many RDs with a high socioeconomic position and a low noise pollution as RDs with a low socioeconomic position and a high noise pollution.

5 Discussion and Conclusion

Since there is no comparable environmental justice research for Austria, the thesis is the first analysis linking the distribution of road traffic noise pollution with spatial socioeconomic inequalities for Vienna, capital of Austria. Zonal statistics were used to specify areas affected by road traffic noise pollution equal or higher than the recommended WHO guideline value of 55 dB Lden for outdoor noise. PCA was applied on socioeconomic data derived from the Viennese population register to evaluate the socioeconomic positon of the neighbourhoods in Vienna. A test for association of road traffic noise affected areas (RTNI) and neighbourhood socioeconomic position (NSPI) by the Pearson correlation coefficient resulted in a weak correlation between the NSPI and the RTNI. Even though there is no citywide environmental injustice concerning road traffic noise, there were twice as many neighbourhoods with a high socioeconomic position and a low noise pollution (double blessing) than neighbourhoods with a low socioeconomic position and a high noise pollution (double burden).

The results reveal an uneven distribution of a double burden/blessing in Vienna, which can be also observed in other cities as e.g. Berlin (Tobias Lakes & Brückner, 2011). As road traffic noise pollution is also highly correlated with air pollution, it has to be assumed that the analysis of the socio-spatial distribution of air pollution would result in similar findings. Thus, it can be argued, that a high socioeconomic position of a neighbourhood in Vienna is a driving force in the access to a good environmental quality.

As environmental justice issues are not on the agenda in city planning organisations or governmental institutions in Vienna or Austria, it has to be assumed that the uneven distribution of environmental pollution is mainly caused by market-based dynamics: people with a high socioeconomic position are more affluent and can escape environmental burdens easier to maximize their utility of living, whereas people with a low socioeconomic position are less affluent and are benefiting from lower property values in environmentally polluted neighbourhoods. Several studies conclude that citizens with a higher education and/or with high-income can be expected in neighbourhoods with a low noise pollution. Havard et al. (2011) argue that those subgroups with a high-income/high socioeconomic position are able to choose freely their residential location and have the money for housing standards offering adequate noise protection. Furthermore Kruize (2007) concludes that noise annoyance avoidance might also be a sign of an active, problem-solving coping that is in theory most often only taken by high-income citizens. Whereas subgroups in social lower position are more exposed to noise annoyance as they tend to complain less about environmental noise due to habituation to chronic residential noise exposure and due to avoiding coping strategies (Kohlhuber et al., 2006).

Even though the uneven distribution may be fair or equitable in economic terms, it is questionable if that uneven distribution is fair or just in terms of human rights. From an environmental justice perspective it is seen as unfair and unjust to legitimate economic discrimination by the 'natural' mechanisms of supply and demand when issues of basic needs are at stake. Furthermore policy strategies which try to increase environmental quality to address environmental justice issues as e.g. increase the supply to urban green space, fail due to market dynamics. Wolch et al. (2014) demonstrated in their study that strategies that try to reduce environmental injustices tend to increase housing costs and property values leading to displacement of residents for those the strategies were designed to benefit from. Therefore, it can be argued that as long as social dynamics are dominated by economic forces, these dynamics will always produce an unequal distribution of 'life chances' which goes along with the production of an unequal distribution of environmental goods and 'bads'. To offset these developments, public awareness on that issue has to be raised and strategic political intervention are needed so that the access to a healthy and secure environment will not become an economic privilege in Vienna.

While the analysis of the distribution of road traffic noise and socioeconomic position leads to explicit results for Vienna, the significance of the results is still limited due to certain methodological issues and data availability. First, the validity of the results is restricted to the registration district level. The analysis may lead to different findings if the analysis was done on the district level or the census district level. This limitation of results is due to the Modifiable Areal Unit Problem (MAUP) that arises in the study of geographic units. The MAUP refers to "*the geographic manifestation of ecological fallacy*", because results based on data aggregated to a particular set of districts may change if one aggregates the same underlying data to a different set of districts (Yang, 2005, p. 1). In general, data aggregated at higher levels of unit e.g. country or city are less reliable and less accurate in determining affected populations than data aggregated by smaller units such as census districts or registrations districts. As there is much variation in demographics and environmental burdens within larger geographic units it is almost impossible to determine environmental burdens and the comparison between the geographic units becomes almost meaningless (Maantay, 2002). Furthermore Glickman and Hersh (1995) also show that the choice of unit of analysis affects most basic findings of an environmental justice study as the modification of geographic boundaries of the study area changes the results of analysis.

Second, for the creation of the NSPI, variables were selected on basis of data availability. Even though the variables selected are in accordance with the socioeconomic positon literature, they do not fully cover the concept of socioeconomic position especially as a variable on income could not be included. In addition, PCA is sensitive to variable selection and number of individuals. On the one hand the PCA approach is strongly data driven and is done in order to use as few constraints as possible. Therefore any data set can be used and a reduction of dimensionality in the data can be computed. On the other hand, this can be seen as a major weakness of the PCA as well. There are no defined methods in choosing the number of variables and components to be included in the PCA (Vyas & Kumaranayake, 2006; Lalloue et al., 2013). Therefore the computed socioeconomic position scores are dependent on the choice of variables and individuals included in the PCA and may change if more/less variables and individuals are included.

Third, data used are area-based and not person-based. Although registration districts are created in order to be as homogeneous as possible, there may be individual variability within them which cannot be evaluated by aggregated data. In addition, the NSPI provides only a relative measure of inequality between areas and it cannot provide information on absolute levels of economic, social or ethnical aspects within Vienna.

Fourth, for the analysis of the noise burden on the RD level, the Lden indicator for outdoor road traffic noise was chosen to represent the objective noise burden only. The Lden indicator is based not only on measurements but also on technical assessments and standardised calculation methods to represent an average sound level for overall noise annoyance (EU, 2002). Although, the Lden appears most often in the literature on environmental noise, it has to be used with some caution when assessing the general noise burden (Ouis, 2001). Actual point measurements of road traffic noise still may differ to the calculated Lden values.

Fifth, for studying the distribution of environmental noise only the Lden values for road traffic noise were taken into account. There are other environmental noise sources in addition to road traffic e.g. rail traffic, air traffic and from sites of industrial activity, so the average sound level and affected area in the registration districts may be higher than calculated for the RTNI.

Sixth, the Lden value does not give any information about the subjective noise burden and noise annoyance. Riedel et al. (2014) argue that the objective road traffic noise exposure does not explain the individuals' subjective noise annoyance properly. In their study they found out that more than two-thirds of the participants exposed to road traffic noise levels higher than 55 dB Lden have not reported being seriously annoyed. In addition, studies suggest that approximately 20% of the variance in noise annoyances measured at the individual level is explained by objective road traffic noise exposure (WHO, 1999a; Kruize, 2007). This may also result from the fact, that the Lden value represents outdoor neighbourhood noise which gives no information about the noise burden due to road traffic noise inside dwellings.

Finally, for linking the RTNI and the NSPI I classified my results in deciles. If I would use other methods for establishing classes as e.g. Hierarchical Clustering or Jenks Optimization, results may differ as well.

Specified and full data on socioeconomic characteristics and environmental pollution of neighbourhoods are needed to compute significant results. The first analysis already revealed an uneven distribution of environmental pollution in favour of neighbourhoods with a high socioeconomic position in Vienna. Significant results and public awareness on environmental justice issues are needed to put it on the political and research agenda so that the access to a healthy and secure environment will not become an economic privilege in Austria.

Bibliography

Abeyasekera, S. (2003). Multivariate methods for index construction. *Household surveys in developing and transition countries: design, implementation and analysis*.

Agyeman, J., & Evans, B. (2004). 'Just sustainability': the emerging discourse of environmental justice in Britain? *The Geographical Journal, 170*(2), 155-164.

Beck, U. (1992). *Risk society: Towards a new modernity* (Vol. 17): Sage.

Been, V. (1992). What's fairness got to do with it? Environmental justice and the siting of locally undesirable land uses. *Cornell L. Rev., 78*, 1001.

Beretta, I. (2012). Some Highlights on the Concept of Environmental Justice and its Use. *e-cadernos ces*(17).

BMLFUW. (2015). Lärmschutz für Österreich Retrieved from http://www.laerminfo.at/

Bocquier, A., Cortaredona, S., Boutin, C., David, A., Bigot, A., Chaix, B., . . . Verger, P. (2013). Small-area analysis of social inequalities in residential exposure to road traffic noise in Marseilles, France. *The European Journal of Public Health, 23*(4), 540-546.

Boer, E., & Schroten, A. (2007). *Traffic noise reduction in Europe: Health effects, social costs and technical and policy options to reduce road and rail traffic noise*: CE Delft, Solutions for environment, economy and technology.

Bosma, H., van de Mheen, H. D., Borsboom, G. J., & Mackenbach, J. P. (2001). Neighborhood socioeconomic status and all-cause mortality. *American Journal of Epidemiology, 153*(4), 363-371.

Brainard, J. S., Jones, A. P., Bateman, I. J., & Lovett, A. A. (2004). Exposure to environmental urban noise pollution in Birmingham, UK. *Urban Studies, 41*(13), 2581-2600.

Brulle, R. J., & Pellow, D. N. (2006). Environmental justice: human health and environmental inequalities. *Annu. Rev. Public Health, 27*, 103-124.

Bullard, R. D. (2000). *Dumping in Dixie: Race, class, and environmental quality* (Vol. 3): Westview Press Boulder, CO.

Bullard, R. D., Mohai, P., Saha, R., & Wright, B. H. (2008). Toxic Wastes and Race at Twenty: Why Race still matters after all of these years. *Envtl. L., 38*, 371.

Bullard, R. D., & Wright, B. H. (1987). Environmentalism and the politics of equity: emergent trends in the black community. *Mid-American Review of Sociology*, 21-37.

Cole, L. W., & Foster, S. R. (2001). *From the ground up: Environmental racism and the rise of the environmental justice movement*: NYU Press.

Commission for Racial Justice. (1987). *Toxic wastes and race in the United States: A national report on the racial and socio-economic characteristics of communities with hazardous waste sites*: United Church of Christ.

Dall, K. (2006). Socio-economic indicators atlas: Toronto Central LHIN.

Debbané, A. M., & Keil, R. (2004). Multiple disconnections: environmental justice and urban water in Canada and South Africa. *Space and Polity, 8*(2), 209-225.

Diekmann, A., & Meyer, R. (2010). Demokratischer Smog? Eine empirische Untersuchung zum Zusammenhang zwischen Sozialschicht und Umweltbelastungen. *KZfSS Kölner Zeitschrift für Soziologie und Sozialpsychologie, 62*(3), 437-457.

EA. (2007). *Addressing environmental inequalities: cumulative environmental impacts*. (SC020061/SR4). Bristol, UK Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291062/scho0507bmrw-e-e.pdf.

Earle, C. (1996). The model of rational economic man and its alternatives: a brief for intermittent rationality. *Concepts in Human Geography, Rowman and Littlefield Publishers, Lanham, MD*, 323-353.

EC. (1996). *Green Paper on Future Noise Policy*. Brussels: EC Retrieved from http://aei.pitt.edu/1204/1/noise_gp_COM_96_540.pdf.

EC. (2013). ANNEX 5: PRINCIPAL COMPONENTS ANALYSIS AND THE WELLBEING INDEX. *Studies for carrying out the Common Fisheries Policy: Lot 3 Socio-economic dimensions in EU fisheries.* Retrieved from http://ec.europa.eu/fisheries/documentation/studies/socio_economic_dimension/index_en.htm

EEA. (2014). *Noise in Europe 2014*. (10/2014). Luxembourg: European Environment Agency.

EEA. (2015). *The European environment: state and outlook 2015*. Copenhagen: European Environment Agency Retrieved from http://www.eea.europa.eu/soer.

EPA. (1992). Environmental Equity: Reducing Risks for All Communities. Retrieved from http://www.epa.gov/compliance/environmentaljustice/resources/reports/annual-project-reports/reducing_risk_com_vol1.pdf

EPA. (2015a). Summary of Executive Order 12898 - Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations. Retrieved from http://www2.epa.gov/laws-regulations/summary-executive-order-12898-federal-actions-address-environmental-justice

EPA. (2015b). What is Environmental Justice? Retrieved from http://www.epa.gov/environmentaljustice/

Esri. (2012). Zonal Statistics (Spatial Analyst) Retrieved from http://resources.arcgis.com/en/help/main/10.1/index.html#//009z000000w7000000

Esri. (2013). Tabulate Intersection (Analysis) Retrieved from http://resources.arcgis.com/en/help/main/10.1/index.html#//000800000044000000

EU. (2001). *Environment 2010: Our Future, Our Choice. 6th EU Environment Action Programme*. Luxembourg: Office for Official Publications of the European Communities Retrieved from http://ec.europa.eu/environment/archives/air/pdf/6eapbooklet_en.pdf.

EU. (2002). Directive 2002/49/EC of the European parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise (OJ L 189, 18.7.2002, p. 12–25). Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002L0049&from=EN

EU. (2013). *Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'*. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013D1386&from=EN.

Farcaş, F., & Sivertunb, Å. (2005). Road traffic noise: GIS tools for noise mapping and a case study for Skåne region.

Finger, M. O., & Zorzi, F. B. (2013). Environmental Justice. *UFRGS Model United Nations Journal, v1*, 222-243.

FoE. (2001). Pollution and Poverty — Breaking the Link. Retrieved from http://www.foe.co.uk/sites/default/files/downloads/pollution_poverty_report.pdf

Galobardes, B., Lynch, J., & Smith, G. D. (2007). Measuring socioeconomic position in health research. *British Medical Bulletin, 81*(1), 21-37.

Glickman, T. S., & Hersh, R. (1995). *Evaluating environmental equity: The impacts of industrial hazards on selected social groups in Allegheny County, Pennsylvania*: Resources for the Future.

Haan, M., Kaplan, G. A., & Camacho, T. (1987). Poverty and health prospective evidence from the alameda county study. *American Journal of Epidemiology, 125*(6), 989-998.

Havard, S., Deguen, S., Bodin, J., Louis, K., Laurent, O., & Bard, D. (2008). A small-area index of socioeconomic deprivation to capture health inequalities in France. *Social Science & Medicine, 67*(12), 2007-2016.

Havard, S., Reich, B. J., Bean, K., & Chaix, B. (2011). Social inequalities in residential exposure to road traffic noise: an environmental justice analysis based on the RECORD Cohort Study. *Occupational and environmental medicine, 68*(5), 366-374.

Hradil, S. (2012). Deutsche Verhältnisse - Eine Sozialkunde. Retrieved from http://www.bpb.de/politik/grundfragen/deutsche-verhaeltnisse-eine-sozialkunde/138437/grundbegriffe

humanrights. (2015). umweltschutz-perspektive-menschenrechte. Retrieved from http://www.humanrights.ch/de/internationale-menschenrechte/nachrichten/menschenrechtsrat/umweltschutz-perspektive-menschenrechte

Husson, F., Lê, S., & Pagès, J. (2010). *Exploratory multivariate analysis by example using R*: CRC press.

Johnson, J. (2012). Environmental Justice. In R. Chadwick (Ed.), *Encyclopedia of Applied Ethics (Second Edition)* (pp. 124-132). San Diego: Academic Press.

Ko, J. H., Chang, S. I., & Lee, B. C. (2011). Noise impact assessment by utilizing noise map and GIS: A case study in the city of Chungju, Republic of Korea. *Applied Acoustics, 72*(8), 544-550.

Köckler, H., Katzschner, L., Kupski, S., Katzschner, A., & Pelz, A. (2008). *Umweltbezogene Gerechtigkeit und Immissionsbelastungen am Beispiel der Stadt Kassel* (Vol. 1): kassel university press GmbH.

Kohlhuber, M., Mielck, A., Weiland, S. K., & Bolte, G. (2006). Social inequality in perceived environmental exposures in relation to housing conditions in Germany. *Environmental research, 101*(2), 246-255.

Krieger, N., Chen, J., Waterman, P., Soobader, M., Subramanian, S., & Carson, R. (2003). Choosing area based socioeconomic measures to monitor social inequalities in low birth weight and childhood lead poisoning: The Public Health Disparities Geocoding Project (US). *Journal of Epidemiology and Community Health, 57*(3), 186-199. doi:10.1136/jech.57.3.186

Krieger, N., Chen, J. T., Waterman, P. D., Soobader, M.-J., Subramanian, S., & Carson, R. (2003). Choosing area based socioeconomic measures to monitor social inequalities in low birth weight and childhood lead poisoning: The Public Health Disparities Geocoding Project (US). *Journal of Epidemiology and Community Health, 57*(3), 186-199.

Krishnan, V. (2010). Constructing an area-based socioeconomic index: A principal components analysis approach. *Edmonton, Alberta: Early Child Development Mapping Project*.

Kruize, H. (2007). On environmental equity: Exploring the distribution of environmental quality among socio-economic categories in the Netherlands. *Netherlands Geographical Studies*(359).

Lakes, T., & Brückner, M. (2011). *Socio-spatial distribution of noise exposure in Berlin*. Berlin: Federal Environmental Agency (UBA) Retrieved from http://www.umweltbundesamt.de/publikationen/umid-022011-special-issue-ii-environmental-justice.

Lakes, T., Brückner, M., & Krämer, A. (2014). Development of an environmental justice index to determine socio-economic disparities of noise pollution and green space in residential areas in Berlin. *Journal of Environmental Planning and Management, 57*(4), 538-556.

Lalloue, B., Monnez, J.-M., Padilla, C., Kihal, W., Le Meur, N., Zmirou-Navier, D., & Deguen, S. (2013). A statistical procedure to create a neighborhood socioeconomic index for health inequalities analysis. *International Journal for Equity in Health, 12*(1), 21. Retrieved from http://www.equityhealthj.com/content/12/1/21

Lam, K.-c., & Chung, Y.-t. T. (2012). Exposure of urban populations to road traffic noise in Hong Kong. *Transportation Research Part D: Transport and Environment, 17*(6), 466-472.

Laurent, E. (2011). Issues in environmental justice within the European Union. *Ecological Economics, 70*(11), 1846-1853. doi:10.1016/j.ecolecon.2011.06.025

Le, S., Josse, J., & Husson, F. (2008). FactoMineR: An R package for multivariate analysis. *J Stat Software, 25*, 1 - 18.

Lynch, J., & Kaplan, G. (2000). *Socioeconomic position*: Social epidemiology. New York: Oxford University Press.

MA 23. (2015a). Magistratsabeitulg 23: Wirtschaft, Arbeit und Statistik. Retrieved from http://www.wien.gv.at/statistik/

MA 23. (2015b). Statistisches Jahrbuch der Stadt Wien 2014. Retrieved from https://www.wien.gv.at/statistik/publikationen/jahrbuch.html

Maantay, J. (2002). Mapping environmental injustices: pitfalls and potential of geographic information systems in assessing environmental health and equity. *Environmental Health Perspectives, 110*(Suppl 2), 161.

Manly, B. F. (2004). *Multivariate statistical methods: a primer*: CRC Press.

Méline, J., Van Hulst, A., Thomas, F., Karusisi, N., & Chaix, B. (2013). Transportation noise and annoyance related to road traffic in the French RECORD study. *International journal of health geographics, 12*(1), 44.

Messer, L. C., Laraia, B. A., Kaufman, J. S., Eyster, J., Holzman, C., Culhane, J., . . . O'campo, P. (2006). The development of a standardized neighborhood deprivation index. *Journal of Urban Health, 83*(6), 1041-1062.

Mielck, A., Koller, D., Bayerl, B., & Spies, G. (2009). Luftverschmutzung und Lärmbelastung: Soziale Ungleichheiten in einer wohlhabenden Stadt wie München. *Sozialer Fortschritt, 58*(2-3), 43-48. doi:10.3790/sfo.58.2-3.43

Mohai, P. (2008). Equity and the environmental justice debate. *Research in social problems and public policy, 15*, 21-49.

Mohai, P., Pellow, D., & Roberts, J. T. (2009). Environmental justice. *Annual Review of Environment and Resources, 34*, 405-430.

Most, M. T., Sengupta, R., & Burgener, M. A. (2004). Spatial Scale and Population Assignment Choices in Environmental Justice Analyses 1. *The Professional Geographer, 56*(4), 574-586.

Nega, T. H., Chihara, L., Smith, K., & Jayaraman, M. (2013). Traffic Noise and Inequality in the Twin Cities, Minnesota. *Human and Ecological Risk Assessment: An International Journal, 19*(3), 601-619.

OECD. (2008). *Handbook on constructing composite indicators: Methodology and user guide*. Retrieved from

Ogneva-Himmelberger, Y., & Cooperman, B. (2010). Spatio-temporal Analysis of Noise Pollution near Boston Logan Airport: Who Carries the Cost? *Urban Studies, 47*(1), 169-182.

Okereke, C. (2006). Global environmental sustainability: Intragenerational equity and conceptions of justice in multilateral environmental regimes. *Geoforum, 37*(5), 725-738.

Ouis, D. (2001). Annoyance from road traffic noise: a review. *Journal of Environmental Psychology, 21*(1), 101-120.

Pastor, M. (2007). *Environmental justice: reflections from the United States* (J. K. Boyce, S. Narain, & E. A. Stanton Eds. Vol. 1).

Pellow, D. N., & Brulle, R. J. (2005). Power, justice, and the environment: A critical appraisal of the environmental justice movement. *MIT Press*, 1-19.

Prettenthaler, F., Habsburg-Lothringen, C., & Sterner, C. (2008). Soziale Aspekte von Climate Change Impacts in Österreich. *Studie im Auftrag von GLOBAL 2000*.

Riedel, N., Scheiner, J., Müller, G., & Köckler, H. (2014). Assessing the relationship between objective and subjective indicators of residential exposure to road traffic noise in the context of environmental justice. *Journal of Environmental Planning and Management, 57*(9), 1398-1421.

Ringquist, E. (2002). Environmental justice: normative concerns, empirical evidence, and governmental action. *Environmental policy: new directions in the 21st century. Congressional Quarterly Press, Washington, DC*.

Roberts, J. T., & Toffolon-Weiss, M. M. (2001). *Chronicles from the environmental justice frontline*: Cambridge University Press.

Salkind, N. J. (2010). *Encyclopedia of research design* (Vol. 1): Sage.

Salmond, C., & Crampton, P. (2002). *NZDep2001 index of deprivation*: Department of Public Health, Wellington School of Medicine and Health Science.

Schwarte, C., & Adebowale, M. (2007). Environmental justice and race equality in the European Union. *Capacity Global*.

Slater, A. M., & Pedersen, O. W. (2009). Environmental justice: lessons on definition and delivery from Scotland. *Journal of Environmental Planning and Management, 52*(6), 797-812. doi:10.1080/09640560903083749

Smith, G. D., & Dorling, D. (1996). " I'm all right, John": voting patterns and mortality in England and Wales, 1981-92. *BMJ: British Medical Journal, 313*(7072), 1573.

Smith, L. I. (2002). A tutorial on principal components analysis. *Cornell University, USA, 51*, 52.

Stadt Wien. (2015a). Open Government Wien. Retrieved from https://open.wien.gv.at/site/

Stadt Wien. (2015b). Zählgebietsgrenzen. Retrieved from https://www.data.gv.at/katalog/dataset/0adc90c9-ac6b-47ef-aa83-b7780594720c

Statistik Austria. (2013). Umweltbedingungen, Umweltverhalten 2011. *Ergebnisse des Mikrozensus.* Retrieved from http://www.statistik.at/web_de/dynamic/services/publikationen/15/publdetail?id=15&listid=15&detail=651

Statistik Austria. (2015a). Integrierte Lohn- und Einkommenssteuerstatistik 2011. Retrieved from http://www.statistik.at/web_de/statistiken/oeffentliche_finanzen_und_steuern/steuerstatistiken/integrierte_lohn-und_einkommensteuerstatistik/index.html

Statistik Austria. (2015b). *Ortsverzeichnis Wien 2001*. Vienna: Statistik Austria Retrieved from http://www.statistik.at/wcm/idc/idcplg?IdcService=GET_PDF_FILE&RevisionSelectionMethod=LatestReleased&dDocName=007110.

Taylor, D. A. (2004). Global resources: abuse, scarcity, and insecurity. *Environmental Health Perspectives, 112*(3), A168.

UMID. (2011). Special Issue II Environmental Justice. *Environment and Human Health – Information Service*.

UNEP. (2015). High Level Expert Meeting on the future of Human Rights and Environment: Moving the Global Agenda Forward. Retrieved from http://www.unep.org/environmentalgovernance/Events/HumanRightsandEnvironment/tabid/2046/Default.aspx

Viel, J. F., Hägi, M., Upegui, E., & Laurian, L. (2011). Environmental justice in a French industrial region: Are polluting industrial facilities equally distributed? *Health & Place, 17*(1), 257-262.

Vyas, S., & Kumaranayake, L. (2006). How to do (or not to do). Constructing socioeconomic status indices: how to use principal components analysis. HIVTools Research Group. *Health Policy Unit, Department of Public Health and Policy, London School of Hygiene and Tropical Medicine,: Published by Oxford University Press in association with The London School of Hygiene and Tropical Medicine*.

Walker, G. (2009). Globalizing Environmental Justice The Geography and Politics of Frame Contextualization and Evolution. *Global Social Policy, 9*(3), 355-382.

WHO. (1999a). *Guidelines for Community Noise*. Geneva and Copenhagen: World Health Organization Regional Office for Europe Retrieved from https://www.google.at/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwi_vODC7c7JAhWCbhoKHdjfAqMQFggfMAA&url=http%3A%2F%2Fwhqlibdoc.who.int%2Fhq%2F1999%2Fa68672.pdf&usg=AFQjCNHq0SRjmXAXPKGPvQC88NtlGaJJBQ&sig2=kkKuVbc6eiH1r4EnTIEO2g&cad=rja.

WHO. (1999b). Guidelines for Community Noise: Guideline Values. Retrieved from http://www.who.int/docstore/peh/noise/Commnoise4.htm

WHO. (2011). *Burden of disease from environmental noise. Quantification of healthy life years lost in Europe*. World Health Organization, Regional Office for Europe Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf.

WHO. (2012). Environmental health inequalities in Europe: Assessment report.

Williams, G., & Mawdsley, E. (2006). Postcolonial environmental justice: Government and governance in India. *Geoforum, 37*(5), 660-670.

Williams, R. W. (1999). Environmental injustice in America and its politics of scale. *Political Geography, 18*(1), 49-73.

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landscape and Urban Planning, 125*, 234-244.

Yang, T.-C. (2005). Modifiable areal unit problem. *GIS Resource Document, 5*, 65.

Appendix

Table A 1: Population number and area (in ha) in Vienna (RD level)

District	Registration District	Population (stand 31.10.2011)	Area (in ha)
1	101	3861	37.7556721
1	102	1550	37.9375273
1	103	2082	46.6465724
1	104	1540	83.4872945
1	105	2091	33.327271
1	106	2635	23.6212211
1	107	2615	24.103021
2	201	10348	180.785396
2	202	11209	37.8312049
2	203	12300	113.577096
2	204	16154	56.0396711
2	205	8964	41.7763043
2	206	6451	366.163916
2	207	12714	38.426103
2	208	2009	837.465583
2	209	15962	127.734998
2	210	2	124.397424
3	301	10874	56.0769636
3	302	8495	51.7405052
3	303	5934	96.5848016
3	304	10488	28.5813094
3	305	7950	50.3634292
3	306	14934	56.8031346
3	307	5223	155.291241
3	308	1717	109.937976
3	309	8558	45.4045185
3	310	7687	39.7098536
3	311	2667	49.2781431
4	401	2254	27.1199806
4	402	9709	67.2513903
4	403	12009	56.2630998
4	404	6728	26.8841349
5	501	11207	53.0018339
5	502	19211	67.1022318
5	503	16051	52.0734665
5	504	6126	28.986965
6	601	7316	47.3167231
6	602	9004	42.1756419
6	603	13055	56.0119369
7	701	5427	28.8466986

7	702	2860	29.0721203
7	703	4495	29.1257499
7	704	9677	42.4875564
7	705	7560	31.2926053
8	801	5343	26.7740856
8	802	10839	52.1908262
8	803	7347	30.0293511
9	901	8150	68.1240077
9	902	10814	47.0825592
9	903	4040	51.5330728
9	904	9055	39.9685015
9	905	5216	50.2694677
9	906	2016	39.7626281
10	1001	899	103.627249
10	1002	18755	79.192011
10	1003	6856	65.7861451
10	1004	7995	36.2750183
10	1005	17185	56.7948745
10	1006	11765	51.2602029
10	1007	11891	34.3157087
10	1008	9472	42.9132899
10	1009	4732	74.0434856
10	1010	16190	64.6249199
10	1011	8940	124.091835
10	1012	2462	131.31511
10	1013	5136	94.079192
10	1014	4045	132.930115
10	1015	5978	215.883821
10	1016	5930	567.496792
10	1017	894	403.221726
10	1018	4356	282.542449
10	1019	2668	296.483908
10	1020	9511	80.267069
10	1021	6564	173.467967
10	1022	6443	23.3417417
10	1023	9322	48.2777648
11	1101	1744	63.6323433
11	1102	13220	109.511708
11	1103	16090	86.2726979
11	1104	4464	113.009036
11	1105	10767	156.500182
11	1106	321	443.648734
11	1107	6592	95.3243757
11	1108	778	133.108768
11	1109	2416	382.14631

11	1110	25208	214.276729
11	1111	4682	190.300901
11	1112	437	262.035415
11	1113	4368	75.8637444
12	1201	3995	29.1047345
12	1202	17185	66.517227
12	1203	5045	55.0694172
12	1204	8266	37.73112
12	1205	8132	42.0027069
12	1206	8532	45.7647921
12	1207	6507	84.0267473
12	1208	4278	66.7510654
12	1209	7961	57.9853146
12	1210	9449	140.121592
12	1211	9153	185.310616
13	1301	464	219.501542
13	1302	6015	135.243514
13	1303	8770	80.391172
13	1304	9995	277.236256
13	1305	4226	133.508952
13	1306	2500	61.4769265
13	1307	3148	43.7986407
13	1308	6306	158.810617
13	1309	4797	148.215302
13	1310	80	2349.54723
13	1311	4325	163.755222
14	1401	6618	52.0467929
14	1402	8283	38.909827
14	1403	8610	93.9035509
14	1404	18920	98.6284715
14	1405	4112	114.126313
14	1406	11837	97.8952305
14	1407	2927	16.4964527
14	1408	3849	111.712688
14	1409	279	100.899331
14	1410	7235	316.997053
14	1411	6448	300.40844
14	1412	5753	2034.23564
15	1501	10365	44.6354065
15	1502	9354	39.6018503
15	1503	11400	68.2754218
15	1504	7347	40.8523527
15	1505	10630	76.8199187
15	1506	13860	52.6943921
15	1507	8330	68.8836885

16	1601	13398	51.152517
16	1602	8074	30.1351335
16	1603	12161	69.3379342
16	1604	8026	38.6402357
16	1605	15265	58.2516299
16	1606	10245	75.1924763
16	1607	9871	42.4366294
16	1608	3430	99.8120453
16	1609	5102	371.802155
16	1610	10122	30.5656881
17	1701	10142	66.9025839
17	1702	13605	63.8600304
17	1703	16861	76.0718741
17	1704	3648	131.144859
17	1705	5880	180.173796
17	1706	2385	620.892408
18	1801	1949	71.2652936
18	1802	13472	81.6996697
18	1803	14467	72.9674182
18	1804	8890	77.5527734
18	1805	8849	331.291798
19	1901	5691	688.231009
19	1902	9510	56.6479214
19	1903	265	61.6617013
19	1904	13219	123.725998
19	1905	6952	149.600087
19	1906	4834	555.3365
19	1907	2844	389.699038
19	1908	12406	72.8778542
19	1909	4159	70.0910843
19	1910	8427	326.569012
20	2001	8161	132.4501
20	2002	15002	96.4606907
20	2003	13449	46.5485396
20	2004	9114	64.7980254
20	2005	10993	43.0234172
20	2006	8374	53.7129303
20	2007	12857	70.8736263
20	2008	5406	63.1813656
21	2101	1337	915.8158
21	2102	7075	117.792852
21	2103	5434	219.503422
21	2104	3905	131.952854
21	2105	18250	316.70387
21	2106	840	71.0282987

21	2107	3452	233.408294
21	2108	2567	156.682459
21	2109	6839	97.8549321
21	2110	4979	51.0999539
21	2111	4824	66.3700774
21	2112	7319	117.368162
21	2113	4615	378.076925
21	2114	4937	68.1244187
21	2115	4229	51.7565031
21	2116	3332	289.51619
21	2117	6438	122.588371
21	2118	6944	40.4215957
21	2119	3173	59.0566846
21	2120	1626	49.5963156
21	2121	6258	42.104815
21	2122	8251	124.026009
21	2123	10230	45.4137761
21	2124	3627	69.465409
21	2125	4552	162.342298
21	2126	6964	58.0373201
21	2127	1478	208.537824
21	2128	286	65.4125833
21	2129	188	41.4980952
21	2130	13	72.7760266
22	2201	2015	497.590654
22	2202	4479	1004.06294
22	2203	1380	436.904171
22	2204	3916	464.614415
22	2205	5058	568.442762
22	2206	11321	182.591297
22	2207	4693	551.002877
22	2208	15753	343.139231
22	2209	13434	125.510822
22	2210	6494	98.7477176
22	2211	10818	388.00155
22	2212	3325	69.890632
22	2213	6507	48.8790307
22	2214	5020	74.3601481
22	2215	8519	86.8814324
22	2216	1156	104.849102
22	2217	1746	208.087777
22	2218	5602	76.5804627
22	2219	5507	43.0082782
22	2220	2944	103.082375
22	2221	1936	59.8306174

22	2222	6227	94.9866609
22	2223	4460	109.799032
22	2224	5768	225.171617
22	2225	1894	60.4827709
22	2226	3789	721.15944
22	2227	6341	321.707198
22	2228	3599	94.792958
22	2229	3413	191.811696
22	2230	15	2608.17974
22	2231	84	29.1000574
22	2232	4206	236.663219
23	2301	2403	104.083816
23	2302	4604	124.879842
23	2303	3503	146.494371
23	2304	7611	147.429286
23	2305	8911	177.887926
23	2306	899	223.07418
23	2307	8716	130.570096
23	2308	4182	146.145268
23	2309	6832	133.172439
23	2310	5123	65.6517844
23	2311	7432	74.8252688
23	2312	5497	118.523335
23	2313	4161	143.146755
23	2314	4788	130.334176
23	2315	2175	174.123826
23	2316	2223	614.232178
23	2317	261	215.725954
23	2318	5466	278.535389
23	2319	9669	58.0323475
Total		1714227	41487.1025

	X0.24	X25.64	X65.	bluecollar	whitecollar	civilservant	selfemployed	unemployed	compulsory	apprenticeship	secondary	college	uni	owner	nonowner	male	female	loneparenthood	X1perunit	X2perunit	X3.5perunit	X6.perunit	overcrowding	austria	serbiamontenegro	Turkey	germany	poland	bosnia	croatia	romania	czechrepublic	hungary	others	nonaustrians
X0.24	1	-0.19	-0.5	0.3	-0.11	-0.02	-0.43	0.13	0.29	0.26	0.06	-0.08	-0.35	-0.19	0.26	-0.14	0.14	0.24	-0.44	0.08	0.47	0.54	0.45	-0.1	0.26	0.4	-0.31	-0.06	0.21	0.27	-0.01	0.15	0.03	-0.1	0.1
X25.64	-0.19	1	-0.75	0.16	0	0.03	-0.06	-0.08	0.23	0.26	0.38	0.07	0.12	-0.06	-0.03	0.66	-0.66	-0.51	0.24	-0.39	-0.01	-0.28	0.07	-0.4	0.22	0.11	0.14	0.4	0.4	0.24	0.38	0.12	0.2	0.35	0.4
X65.	-0.5	-0.75	1	-0.34	0.07	-0.01	0.34	-0.01	-0.4	-0.4	-0.37	0	0.13	0.18	-0.15	-0.49	0.49	0.29	0.08	0.29	-0.31	-0.12	-0.36	0.42	-0.37	-0.36	0.08	-0.32	-0.49	-0.39	-0.33	-0.21	-0.2	-0.24	-0.42
bluecollar	0.3	0.16	-0.34	1	-0.81	-0.34	-0.67	0.6	0.95	0.56	-0.56	-0.66	-0.72	-0.41	0.38	0.42	-0.42	-0.12	0.18	-0.27	-0.11	0.28	0.61	-0.53	0.69	0.7	-0.53	0.48	0.63	0.54	0.45	-0.03	0.03	0.16	0.53
whitecollar	-0.11	0	0.07	-0.81	1	0.36	0.4	-0.68	-0.85	-0.31	0.76	0.69	0.55	0.37	-0.31	-0.42	0.42	0.05	-0.22	0.22	0.2	-0.34	-0.56	0.53	-0.63	-0.61	0.34	-0.29	-0.54	-0.48	-0.39	0.13	-0.11	-0.3	-0.53
civilservant	-0.02	0.03	-0.01	-0.34	0.36	1	-0.24	-0.42	-0.41	0.39	0.52	0.12	-0.16	0.4	-0.43	0	0	-0.15	-0.55	0.45	0.48	-0.22	-0.25	0.66	-0.52	-0.51	-0.34	-0.27	-0.23	-0.48	-0.38	-0.13	-0.36	-0.59	-0.66
selfemployed	-0.43	-0.06	0.34	-0.67	0.4	-0.24	1	-0.4	-0.58	-0.77	0.11	0.46	0.84	0.13	-0.16	-0.22	0.22	0.2	0.26	-0.17	-0.22	-0.15	-0.4	-0.04	-0.23	-0.35	0.75	-0.12	-0.31	-0.13	-0.04	-0.03	0.11	0.34	0.04
unemployed	0.13	-0.08	-0.01	0.6	-0.68	-0.42	-0.4	1	0.67	0.15	-0.57	-0.44	-0.42	-0.39	0.38	0.19	-0.19	-0.05	0.21	-0.32	-0.09	0.2	0.35	-0.27	0.38	0.47	-0.25	0.1	0.27	0.32	0.14	-0.01	0.06	0.08	0.27
compulsory	0.29	0.23	-0.4	0.95	-0.85	-0.41	-0.58	0.67	1	0.48	-0.58	-0.63	-0.63	-0.41	0.38	0.47	-0.47	-0.18	0.2	-0.32	-0.09	0.33	0.69	-0.6	0.75	0.76	-0.43	0.41	0.67	0.6	0.46	-0.05	0.09	0.25	0.6
apprenticeship	0.26	0.26	-0.4	0.56	-0.31	0.39	-0.77	0.15	0.48	1	0.04	-0.47	-0.86	0.07	-0.06	0.44	-0.44	-0.28	-0.43	0.21	0.42	0.19	0.32	0.16	0.03	0.07	-0.8	0.21	0.17	-0.02	0.13	-0.13	-0.28	-0.32	-0.16
secondary	0.06	0.38	-0.37	-0.56	0.76	0.52	0.11	-0.57	-0.58	0.04	1	0.6	0.26	0.34	-0.32	0	0	-0.15	-0.39	0.2	0.44	-0.25	-0.42	0.36	-0.42	-0.44	0.09	-0.17	-0.22	-0.26	-0.21	0.17	-0.02	-0.23	-0.36
college	-0.08	0.07	0	-0.66	0.69	0.12	0.46	-0.44	-0.63	-0.47	0.6	1	0.59	0.26	-0.19	-0.31	0.31	0.06	-0.06	0.07	0.07	-0.26	-0.35	0.17	-0.29	-0.34	0.45	-0.2	-0.33	-0.16	-0.18	0.24	0.15	-0.01	-0.17
uni	-0.35	0.12	0.13	-0.72	0.55	-0.16	0.84	-0.42	-0.63	-0.86	0.26	0.59	1	0.06	-0.1	-0.26	0.26	0.09	0.37	-0.25	-0.29	-0.35	-0.44	-0.08	-0.22	-0.3	0.88	-0.13	-0.23	-0.13	-0.1	0.15	0.24	0.35	0.08
owner	-0.19	-0.06	0.18	-0.41	0.37	0.4	0.13	-0.39	-0.41	0.07	0.34	0.26	0.06	1	-0.96	0.12	-0.12	-0.44	-0.46	0.3	0.42	0.03	-0.18	0.36	-0.39	-0.41	-0.05	-0.1	-0.35	-0.4	-0.12	-0.19	-0.13	-0.19	-0.36
nonowner	0.26	-0.03	-0.15	0.38	-0.31	-0.43	-0.16	0.38	0.38	-0.06	-0.32	-0.19	-0.1	-0.96	1	-0.25	0.25	0.48	0.39	-0.21	-0.4	0.02	0.23	-0.29	0.36	0.42	0.01	0.02	0.25	0.36	0.05	0.22	0.13	0.13	0.29
male	-0.14	0.66	-0.49	0.42	-0.42	0	-0.22	0.19	0.47	0.44	0	-0.31	-0.26	0.12	-0.25	1	-1	-0.61	0.05	-0.31	0.14	0.11	0.11	-0.41	0.24	0.16	-0.2	0.44	0.46	0.23	0.49	-0.09	0.11	0.42	0.41
female	0.14	-0.66	0.49	-0.42	0.42	0	0.22	-0.19	-0.47	-0.44	0	0.31	0.26	-0.12	0.25	-1	1	0.61	-0.05	0.31	-0.14	-0.11	-0.11	0.41	-0.24	-0.16	0.2	-0.44	-0.46	-0.23	-0.49	0.09	-0.11	-0.42	-0.41
loneparenthood	0.24	-0.51	0.29	-0.12	0.05	-0.15	0.2	-0.05	-0.18	-0.28	-0.15	0.06	0.09	-0.44	0.48	-0.61	0.61	1	0.01	0.21	-0.18	0.06	-0.09	0.14	-0.04	-0.08	0.11	-0.26	-0.21	-0.04	-0.29	0.09	-0.11	-0.1	-0.14
X1perunit	-0.44	0.24	0.08	0.18	-0.22	-0.55	0.26	0.21	0.2	-0.43	-0.39	-0.06	0.37	-0.46	0.39	0.05	-0.05	0.01	1	-0.67	-0.85	-0.38	0	-0.55	0.36	0.29	0.42	0.41	0.22	0.31	0.35	0.22	0.3	0.48	0.55
X2perunit	0.08	-0.39	0.29	-0.27	0.22	0.45	-0.17	-0.32	-0.32	0.21	0.2	0.07	-0.25	0.3	-0.21	-0.31	0.31	0.21	-0.67	1	0.2	0.11	-0.05	0.56	-0.33	-0.32	-0.25	-0.57	-0.28	-0.34	-0.48	-0.17	-0.16	-0.46	-0.56
X3.5perunit	0.47	-0.01	-0.31	-0.11	0.2	0.48	-0.22	-0.09	-0.09	0.42	0.44	0.07	-0.29	0.42	-0.4	0.14	-0.14	-0.18	-0.85	0.2	1	0.3	-0.03	0.39	-0.29	-0.21	-0.37	-0.15	-0.11	-0.21	-0.17	-0.17	-0.31	-0.37	-0.39
X6.perunit	0.54	-0.28	-0.12	0.28	-0.34	-0.22	-0.15	0.2	0.33	0.19	-0.25	-0.26	-0.35	0.03	0.02	0.11	-0.11	0.06	-0.38	0.11	0.3	1	0.38	-0.15	0.18	0.27	-0.27	-0.04	0.05	0.16	0.18	-0.07	0.01	0.16	0.15
overcrowding	0.45	0.07	-0.36	0.61	-0.56	-0.25	-0.4	0.35	0.69	0.32	-0.42	-0.35	-0.44	-0.18	0.23	0.11	-0.11	-0.09	0	-0.05	-0.03	0.38	1	-0.48	0.65	0.71	-0.28	0.2	0.45	0.54	0.33	0.02	0.15	0.16	0.48
austria	-0.1	-0.4	0.42	-0.53	0.53	0.66	-0.04	-0.27	-0.6	0.16	0.36	0.17	-0.08	0.36	-0.29	-0.41	0.41	0.14	-0.55	0.56	0.39	-0.15	-0.48	1	-0.81	-0.71	-0.25	-0.59	-0.68	-0.74	-0.72	-0.18	-0.49	-0.81	-1
serbiamontenegro	0.26	0.22	-0.37	0.69	-0.63	-0.52	-0.23	0.38	0.75	0.03	-0.42	-0.29	-0.22	-0.39	0.36	0.24	-0.24	-0.04	0.36	-0.33	-0.29	0.18	0.65	-0.81	1	0.81	-0.02	0.37	0.78	0.81	0.49	0.13	0.27	0.39	0.81
Turkey	0.4	0.11	-0.36	0.7	-0.61	-0.51	-0.35	0.47	0.76	0.07	-0.44	-0.34	-0.3	-0.41	0.42	0.16	-0.16	-0.08	0.29	-0.32	-0.21	0.27	0.71	-0.71	0.81	1	-0.17	0.32	0.65	0.68	0.45	0.12	0.29	0.3	0.71
germany	-0.31	0.14	0.08	-0.53	0.34	-0.34	0.75	-0.25	-0.43	-0.8	0.09	0.45	0.88	-0.05	0.01	-0.2	0.2	0.11	0.42	-0.25	-0.37	-0.27	-0.28	-0.25	-0.02	-0.17	1	-0.08	-0.1	0.04	-0.01	0.14	0.27	0.43	0.25
poland	-0.06	0.4	-0.32	0.48	-0.29	-0.27	-0.12	0.1	0.41	0.21	-0.17	-0.2	-0.13	-0.1	0.02	0.44	-0.44	-0.26	0.41	-0.57	-0.15	-0.04	0.2	-0.59	0.37	0.32	-0.08	1	0.27	0.34	0.75	0.02	0.07	0.4	0.59
bosnia	0.21	0.4	-0.49	0.63	-0.54	-0.23	-0.31	0.27	0.67	0.17	-0.22	-0.33	-0.23	-0.35	0.25	0.46	-0.46	-0.21	0.22	-0.28	-0.11	0.05	0.45	-0.68	0.78	0.65	-0.1	0.27	1	0.72	0.35	0.07	0.2	0.33	0.68
croatia	0.27	0.24	-0.39	0.54	-0.48	-0.48	-0.13	0.32	0.6	-0.02	-0.26	-0.16	-0.13	-0.4	0.36	0.23	-0.23	-0.04	0.31	-0.34	-0.21	0.16	0.54	-0.74	0.81	0.68	0.04	0.34	0.72	1	0.42	0.15	0.28	0.38	0.74
romania	-0.01	0.38	-0.33	0.45	-0.39	-0.38	-0.04	0.14	0.46	0.13	-0.21	-0.18	-0.1	-0.12	0.05	0.49	-0.49	-0.29	0.35	-0.48	-0.17	0.18	0.33	-0.72	0.49	0.45	-0.01	0.75	0.35	0.42	1	0.02	0.37	0.57	0.72
czechrepublic	0.15	0.12	-0.21	-0.03	0.13	-0.13	-0.03	-0.01	-0.05	-0.13	0.17	0.24	0.15	-0.19	0.22	-0.09	0.09	0.09	0.22	-0.17	-0.17	-0.07	0.02	-0.18	0.13	0.12	0.14	0.02	0.07	0.15	0.02	1	0.24	0.16	0.18
hungary	0.03	0.2	-0.2	0.03	-0.11	-0.36	0.11	0.06	0.09	-0.28	-0.02	0.15	0.24	-0.13	0.13	0.11	-0.11	-0.11	0.3	-0.16	-0.31	0.01	0.15	-0.49	0.27	0.29	0.27	0.07	0.2	0.28	0.37	0.24	1	0.53	0.49
others	-0.1	0.35	-0.24	0.16	-0.3	-0.59	0.34	0.08	0.25	-0.32	-0.23	-0.01	0.35	-0.19	0.13	0.42	-0.42	-0.1	0.48	-0.46	-0.37	0.16	0.16	-0.81	0.39	0.3	0.43	0.4	0.33	0.38	0.57	0.16	0.53	1	0.81
nonaustrians	0.1	0.4	-0.42	0.53	-0.53	-0.66	0.04	0.27	0.6	-0.16	-0.36	-0.17	0.08	-0.36	0.29	0.41	-0.41	-0.14	0.55	-0.56	-0.39	0.15	0.48	-1	0.81	0.71	0.25	0.59	0.68	0.74	0.72	0.18	0.49	0.81	1

*red: negative correlation =< - 0.5, green: positive correlation >= 0.5

Figure A 1: Correlation matrix without outlier (RD level)

Table A 2: NSPI scores for each RD

RD	Scores
101	-1.478348532
102	-1.14822807
103	-0.731526361
104	-0.960171035
105	-1.76113389
106	-1.635645843
107	-1.338587961
201	0.842279693
202	3.316856027
203	-0.222495508
204	2.28180681
205	0.893352684
206	0.236474802
207	3.175481945
208	1.555972333
209	2.981888621
210	OUTLIER
301	-0.774881272
302	-2.015340927
303	-0.961788218
304	1.747871255
305	-1.197074165
306	0.385425021
307	1.405424386
308	-0.03807908
309	-1.81934215
310	2.80660755
311	2.652511822
401	-0.718109916
402	-0.647498394
403	-1.212824489
404	-0.172485903
501	-0.758790693
502	2.469946784
503	2.525126493
504	-0.322090237
601	-1.190263778
602	-0.362360605
603	-1.391619688
701	-1.271282549
702	-2.397725315
703	-1.989268653
704	-1.215664955
705	-0.727425892
801	-0.440727068
802	-2.057179519
803	-1.34534125
901	-0.51159087
902	-0.943275846
903	-0.446263976
904	-0.170923065
905	-1.866724535
906	-1.446254599
1001	4.014521583
1002	5.449423938
1003	3.351459907
1004	5.084296488
1005	3.763274296
1006	5.880823221
1007	2.057900586
1008	4.324050203
1009	1.587474063
1010	3.689162277
1011	2.629236843
1012	-3.469316878
1013	0.53065295
1014	0.309457703
1015	-1.527824231
1016	-1.213138886
1017	-3.609914593
1018	-3.822105264
1019	-2.422802737
1020	1.791320549
1021	-1.675936
1022	3.236523449
1023	3.754677197
1101	-3.270326169
1102	3.226885492
1103	3.377403
1104	2.709804001
1105	0.905089917
1106	-1.513677367
1107	1.017740595
1108	-4.35702938
1109	-1.724919823
1110	0.508315651
1111	3.953166721
1112	2.56509204
1113	-1.393751043
1201	3.319152075
1202	3.309513385
1203	5.324536587
1204	2.771718905
1205	1.710796054
1206	1.317431588
1207	1.0322168
1208	2.448800341
1209	4.59891895
1210	-0.296854827
1211	-1.924543379
1301	-2.662412413
1302	-2.418413665
1303	-2.144699392
1304	-2.497148549
1305	-2.706559212
1306	-2.793734816
1307	-0.755330635
1308	-2.42463402
1309	-0.910158616
1310	-2.337146297
1311	-3.523927895
1401	-0.295054931
1402	3.465416572

1403	-0.351763629
1404	0.995824329
1405	-1.47119218
1406	-0.44497024
1407	2.656516816
1408	-1.175584087
1409	7.016173594
1410	-2.479926472
1411	-3.817555377
1412	-2.973649058
1501	2.042103437
1502	3.94125225
1503	4.10803059
1504	4.161316287
1505	2.440202943
1506	3.896007999
1507	1.858719494
1601	3.332114764
1602	5.21188172
1603	2.162775078
1604	1.630700559
1605	1.948765586
1606	1.596512988
1607	0.776123854
1608	-1.662373692
1609	-3.871742422
1610	5.865387778
1701	2.052233558
1702	2.557910918
1703	2.120346768
1704	-2.109083734
1705	-1.845839359
1706	-2.3642019
1801	-2.116055473
1802	-0.967218859
1803	0.88394973
1804	-1.254130691
1805	-2.294355285
1901	-1.160753671

1902	0.957673555
1903	-1.869010734
1904	-0.366095119
1905	-0.745972611
1906	-2.436811704
1907	-2.692460508
1908	-1.094440917
1909	-0.821351875
1910	-2.004328012
2001	2.729038099
2002	3.980112614
2003	3.070454485
2004	1.55263852
2005	3.984618144
2006	3.146829971
2007	2.470993082
2008	2.844074872
2101	-2.679325867
2102	-2.475253492
2103	-2.502003903
2104	-1.687048561
2105	2.231413334
2106	-0.466046679
2107	-0.388273171
2108	0.025569974
2109	0.116423557
2110	2.962774981
2111	-1.238795657
2112	1.949044022
2113	-3.588367699
2114	1.581810572
2115	-1.96237678
2116	-3.655417946
2117	3.040309392
2118	1.017291991
2119	0.233397717
2120	1.872780863
2121	2.808858031
2122	0.676014949

2123	1.064174675
2124	-1.634299521
2125	-2.145631177
2126	-0.774771103
2127	-1.471922966
2128	5.825158425
2129	-1.267721314
2130	4.615584299
2201	-3.350911614
2202	-3.299068557
2203	-2.268805789
2204	-2.995207274
2205	-3.901645449
2206	0.229548423
2207	-3.577739097
2208	0.977944737
2209	0.626808175
2210	-1.80897581
2211	-0.042382862
2212	0.170019894
2213	0.233089609
2214	-1.983024169
2215	1.122750019
2216	0.264692656
2217	-3.982426942
2218	-1.678020048
2219	1.474948037
2220	1.126584828
2221	-2.503515421
2222	-2.127289091
2223	-1.884334213
2224	-2.954560358
2225	-4.152274338
2226	-2.530296855
2227	-3.529793272
2228	-3.582533559
2229	-2.493218656
2230	1.745872279
2231	1.047377762

2232	-2.568671404
2301	-1.203109098
2302	-0.691668779
2303	-2.032460773
2304	-0.696760226
2305	-0.739068055
2306	-1.609141093

2307	-0.310247283
2308	-1.793252401
2309	-1.176976978
2310	-0.070751106
2311	-1.566001443
2312	-0.791906969
2313	-2.945881855

2314	-2.472170714
2315	-3.292183672
2316	-2.077353315
2317	-0.344278063
2318	-1.750883795
2319	-2.838198075

Technical implementation of the data processing for creation of the RTNI inArcGIS 10.2

The Lden value data are available as noise zones polygons in 5 dB ranges and projected as vector data in the MGI_Austria_Lambert coordinate system. Furthermore the Lden values are separately calculated for road traffic noise generated by local streets and highways.

The RD boundaries data are available as polygons and are projected as vector data in the WGS 84 coordinate system.

Before I started with the data manipulation I had to transform the road traffic noise data from the MGI_Austria_Lambert coordinate system into the WGS 84 coordinate system to ensure that all the data are assigned to the same geographic coordinate reference system. Otherwise the data would have different positions and do not overlay so further data processing would not be possible. Figure A 2 illustrates the flow diagram of the data processing in ArcGIS.

The road traffic noise data generated from local streets and highways are available in two separate shapefiles. Although the data description states that the file for local streets also includes highways (BMLFUW, 2015), I discovered that two different values had been calculated for some streets. This circumstance appears to result from the separate calculation methods of the Lden values for local streets and highways and a different classification of streets in two files.

I decided to merge the two files into one single data file. Therefore I converted the vector data into raster data to perform the tool Cell Statistics. With this tool I was able to determine the maximum Lden values for the same position and to merge both files into one data file. After this I converted the raster data back into vector data. To simplify the new polygon structure of the noise zones, I used the tool Dissolve as further tools would only accept combined polygons with the same Lden values.

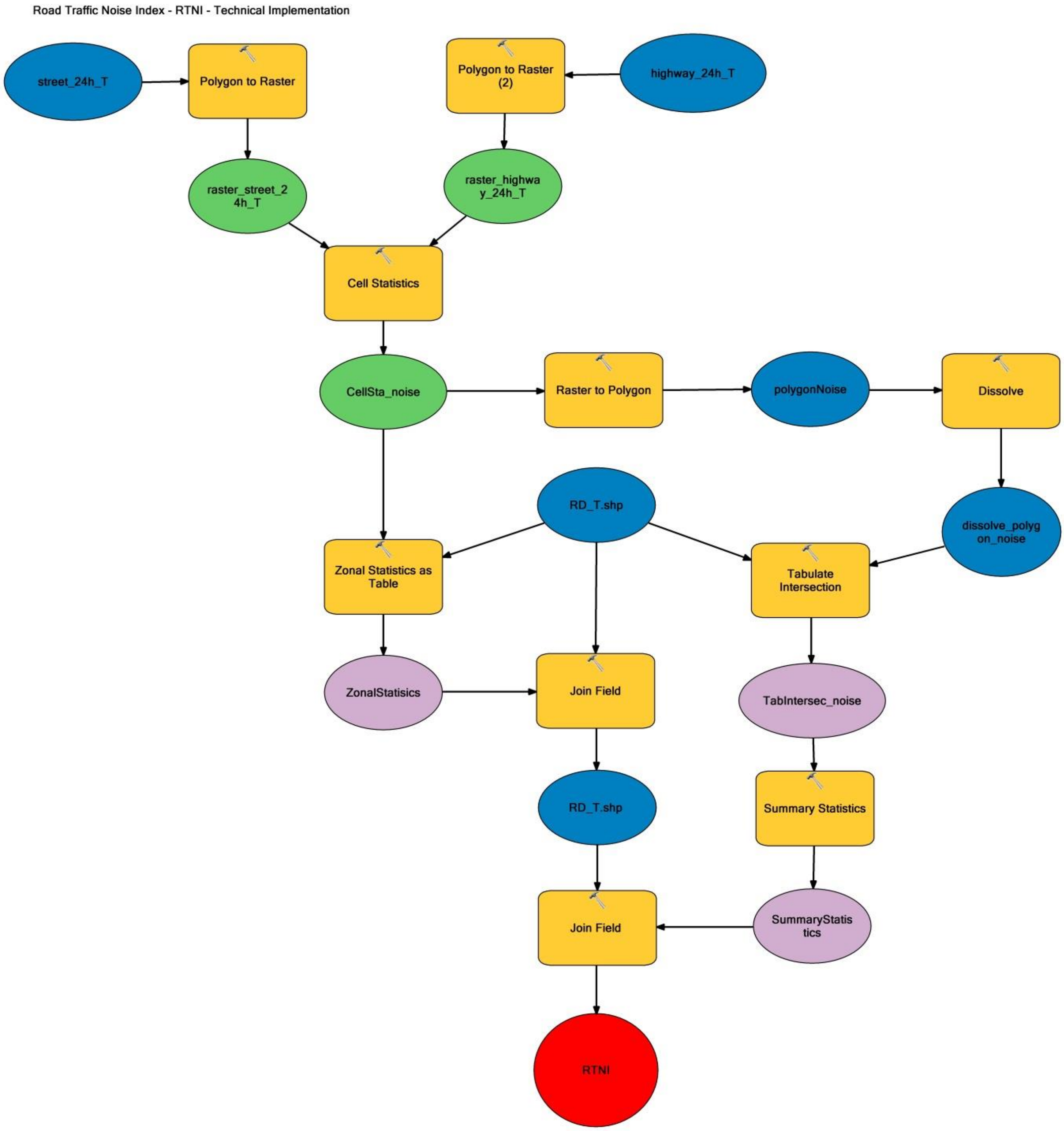
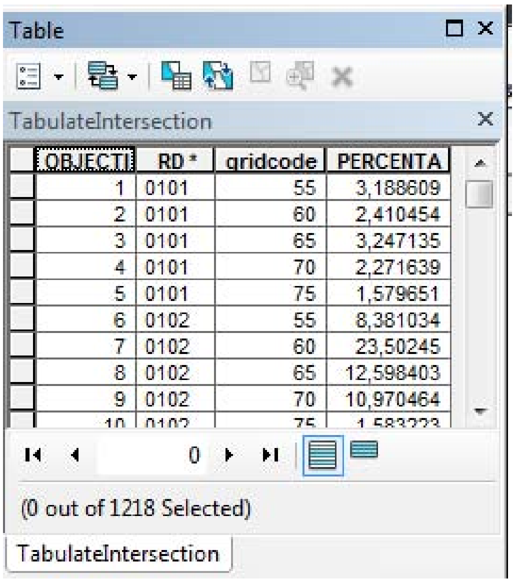


Figure A 2: Flow diagram of the technical implementaion of the RTNI in ArcGIS 10.2

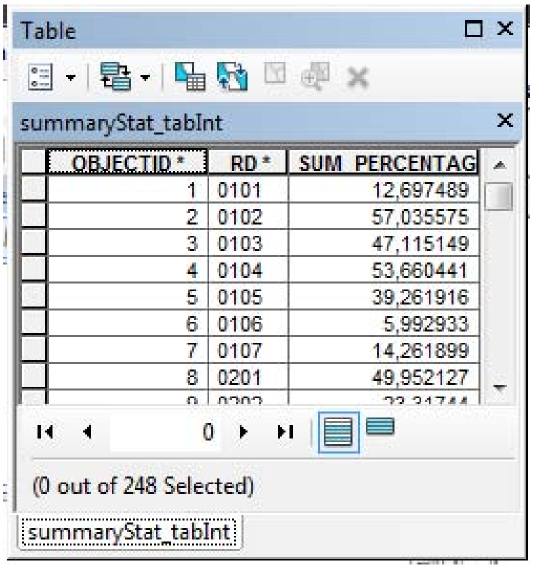
With the noise polygons and the subdistrict polygons, I applied the tool Tabulate Intersection. The tool calculated for each Lden noise range [dB] the percentage of affected area in each RD. A section of the results is shown in Figure A 3.



OBJECTI	RD *	gridcode	PERCENTA
1	0101	55	3,188609
2	0101	60	2,410454
3	0101	65	3,247135
4	0101	70	2,271639
5	0101	75	1,579651
6	0102	55	8,381034
7	0102	60	23,50245
8	0102	65	12,598403
9	0102	70	10,970464

Figure A 3: Tool tabulate intersection - Results

With the tool Summary Statistics I calculated the total percentage of road traffic noise affected area for each RD (Figure A 4). I joined the output table with the RD polygon layer.



OBJECTID *	RD *	SUM_PERCENTAG
1	0101	12,697489
2	0102	57,035575
3	0103	47,115149
4	0104	53,660441
5	0105	39,261916
6	0106	5,992933
7	0107	14,261899
8	0201	49,952127

Figure A 4: Tool summary statistics - Results

With the tool Zonal Statistics as Table I was able to do further analysis of the road traffic noise distribution on the RD level as it summarises statistical values of the noise raster within the RD zones and reports the results to a table (Figure A 5).

Table

ZonalSt_all

OBJECTID *	RD *	MIN	MAX	RANGE	MEAN	STD	VARIETY	MAJORITY	MINORITY	MEDIAN
49	0101	55	75	20	63,636164	6,721402	5	55	75	65
65	0102	55	75	20	62,69522	5,235253	5	60	75	60
143	0103	55	75	20	64,933412	6,239823	5	70	75	65
22	0104	55	75	20	60,219223	4,920636	5	55	75	60
225	0105	55	75	20	64,103121	5,785269	5	65	75	65
133	0106	55	65	10	59,272391	4,067324	3	55	65	60
114	0107	55	75	20	63,851231	5,656705	5	65	75	65
137	0201	55	75	20	59,724033	5,19337	5	55	75	60
30	0202	55	70	15	59,716713	4,121744	4	55	70	60
136	0203	55	75	20	61,946243	5,209863	5	65	75	60
60	0204	55	75	20	62,310045	5,770608	5	65	75	65
157	0205	55	75	20	65,725726	5,035743	5	65	75	65
115	0206	55	85	30	60,48738	6,497137	7	55	85	60
112	0207	55	65	10	56,023039	2,215279	3	55	65	55
218	0208	55	90	35	61,297037	5,708611	8	60	90	60

0 (0 out of 248 Selected)

ZonalSt_all

Figure A 5: Tool zonal statistics - Results

In the last step both statistics are joined to the RD polygon – RTNI – which contains the values for the RTNI and further mapping.