Amsterdam University College

Bachelor Thesis

Analysing evidence-based policy measures to combat air pollution in Amsterdam

Towards compliance with EU standards in 2015

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MILIEU DEFENSIE

“Water and air, the two essential fluids on which all life depends, have become global garbage cans”

Jacques-Yves Cousteau (1910-1997), French oceanographer

“It isn’t pollution that’s harming the environment. It’s the impurities in our air and water that are doing it.”

Dan Quayle (1947-), former Republican vice-president US

Abstract

Air pollution is a persistent issue in urban areas around the globe. This thesis focuses on the air pollutant nitrogen dioxide (NO_2) in the city of Amsterdam (*see Figure 1*). Currently, the limit value of 40 µg/m^3 for nitrogen dioxide is exceeded at many locations in Amsterdam. By January 1, 2015 Amsterdam has to comply with EU legislation. The need for action also stems from the fact that air pollution has been linked to increased mortality rates and respiratory illnesses such as asthma. To map the health impact of air pollution in Amsterdam, this thesis delves into NO_2 concentrations (exposure) by means of an exposure model for air pollution first. The second component of impact is vulnerability, which will be examined by means of a spatial analysis.

It was found that traffic is the only significant predictor of NO_2 exposure in Amsterdam. In particular the elderly and citizens with less income are vulnerable for the health impact of air pollution. The current set of policy measures needs to be intensified or broadened in order to comply with EU legislation in 2015. This thesis proposes to add policy measures with respect to buses, touring cars and mopeds, since these type of vehicles are currently excluded from policy measures. Yet, they have an important contribution to air pollution in the city. Additionally, it is recommended that the group of old and highly polluting vehicles is addressed. Although these interventions will never be implemented in time, this thesis serves the purpose to analyse the path of action that could be taken to comply with EU standards in the near future.

Keywords: air pollution, NO_2, health impact, policy measures, Amsterdam

Figure 1: The location of Amsterdam within the Netherlands.

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Introduction

Air pollution is a persistent issue in urban areas around the globe since medieval times (Brimblecombe, 1977). Increased industrial activity with limited regulation following the Industrial Revolution worsened air quality (Stern, 1973). Nowadays, air pollution in global cities is a frequently recurring topic in the media. Recently, the World Health Organization concluded that air pollution is the single biggest environmental health risk linked to 7 million deaths per year worldwide (WHO, 2014). Presently, the main anthropogenic sources of air pollution are traffic, power plants and industry. In residential urban areas, the dominant source of air pollution is traffic (Schaap et al., 2010; Beijk et al., 2010). Traffic related air pollution does not only originate from fuel combustion, but also from outwear of brakes, tires and the road surface. The associated emission consists of a variety of particles such as carbon oxides, nitrogen oxides, particulate matter (PM) and soot. In the literature NO_2 is often taken as an indicator that represents this mixture of particles (Fischer et al., 2000).

Air pollution has been associated with pressing problems on a regional and global scale. On a regional scale, air pollution has been linked to increased mortality rates and respiratory illnesses such as asthma (Jalaludin et al., 2004; Lee et al., 2007; Schwartz, 1994). On a global scale, emissions play an important role in ozone depletion, global warming and climate change (Dyominov & Zadorozhny, 2005; Kinney, 2008; Ramanathan & Feng, 2009). In response to these pressing problems, governments around the globe have enforced air quality standards. For monitoring compliance of standards among others, exposure models for urban air pollution are crucial. Exposure models make predictions about the concentration of an air pollutant in a certain area based on measurement data from ground stations.

The role of exposure models is to gain deeper insight into how spatial variables such as trees, traffic intensity and distance to road explain the spatial distribution of air pollution. Improved exposure models lead to better health risk assessment and more accurate monitoring of air quality standards (Briggs et al., 1997). Additionally, improved models contribute to the evaluation of government policies with respect to emitters such as transport and industry. For these reasons, policy-makers, NGOs and public health organizations are increasingly interested in exposure models.

This bachelor thesis will focus on the spatial patterns of NO_2 concentration in Amsterdam. Amsterdam is representative of world cities that have difficulty meeting air quality standards. Although air quality standards around the globe differ, the need for the implementation of policy measures to comply with standards does not.

Last year the Netherlands Institute for Public Health and the Environment warned that Dutch urban areas might not be able to comply with the European Union standards for NO_2 concentration by 2015 (RIVM, 2013). The limit value for NO_2 as proposed by the European Commission and adopted by the European Parliament and the Council is 40 $\mu g/m^3$. The limit value relates to the average of a calendar year (European Commission, 2008, p. 30). At the same time, one hour averages may not exceed 200 $\mu g/m^3$. The limit values are said to be health-based standards. These limit values entered into force on

January 1, 2010, but Member States could apply for an extension of up to five years. For this reason, the Netherlands have to comply with these limit values only from January 1, 2015 onwards.

However, at this point in time, large urban areas in the Netherlands have trouble meeting these standards. In Amsterdam, the Municipal Health Service (GGD) is the local organization charged with air pollution measurements. At 40% of their 104 measurement stations spread throughout Amsterdam, the GGD Amsterdam found that the yearly average exceeded the EU standard of 40 µg/m^3 in 2012 (Helmink et al., 2013, p. 113-115). In view of the approaching deadline for EU standards compliance in 2015, there is a large need for an assessment of the current policy measures and recommendations for potential additions or adjustments.

Purpose and objectives

The purpose of my bachelor thesis is fourfold. Firstly, to quantify urban air pollution exposure for the Amsterdam area enclosed by the A10 ring road. Secondly, to research the diverging impact of air pollution on citizens with different socioeconomic status. Thirdly, to apply this relation to the area of Amsterdam. Fourthly and lastly, to conclude with a set of evidence-based recommendations regarding policy measures that control air pollution most effectively given the answers to the previous three points.

This purpose can be expressed in following specific objectives:

1. Build a land use regression model for air pollution exposure in Amsterdam.
2. Analyse the relation between socioeconomic status and health impact of air pollution exposure.
3. Apply this relation in a spatial analysis to the Amsterdam area and produce an impact map.
4. Evaluate and compare several policy measures that aim at reducing air pollution in Amsterdam.

Thesis outline

The four objectives form the chapters of my bachelor thesis and are linked through a framework borrowed from Haines et al. (2006). This framework considers (health) impact to be the multiplication of exposure and vulnerability. Chapter 1 gives an introduction to NO_2 as an air pollutant. The exposure of Amsterdam to air pollution is modeled in Chapter 2. Subsequently, Chapter 3 discusses vulnerability of different groups to air pollution in general. This relation between vulnerability and groups is applied to the city of Amsterdam in Chapter 4 that also provides the impact map for air pollution. Given this analysis, in Chapter 5 evidence-based policy recommendations are discussed.

The linkages of this framework are reflected in the following flow diagram:

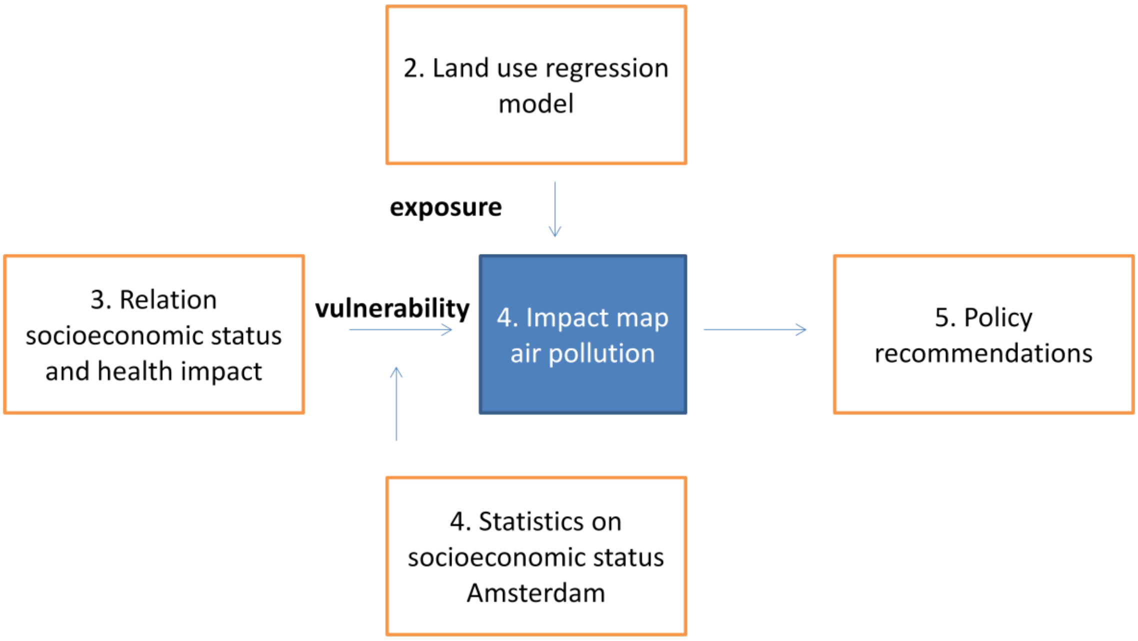


Figure 2: Flow diagram of how the chapters of this thesis relate to each other.

In terms of Lasswell's (1971) policy cycle depicted in Figure 3, Chapters 2, 3 and 4 aim at Problem identification. Chapter 5 discusses both Evaluation of current policy and possible Policy formulation of new policy.

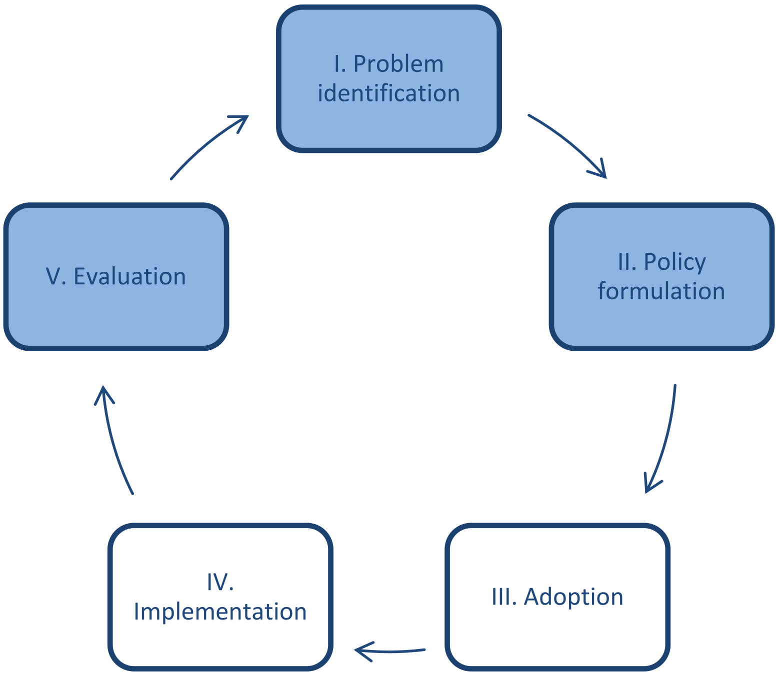


Figure 3: Laswell's policy cycle that outlines the different stages a policy moves through.

Chapter 1: Background - the urban air pollutant NO_2

In this chapter the background for this bachelor thesis will be sketched. The reasons for choosing NO_2 as unit of analysis will be listed first. Then the different sources of NO_2 emissions are one by one examined. Lastly, the main source of NO_2 emissions, notably traffic, will be discussed in greater detail.

1.1 Why nitrogen dioxide as unit of analysis?

Air pollution has been associated with pressing problems on a regional and global scale. On a regional scale, air pollution has been linked to increased mortality rates and respiratory illnesses such as asthma (Jalaludin et al., 2004; Lee et al., 2007; Schwartz, 1994). On a global scale, air pollutant emissions play an important role in ozone depletion, global warming and climate change (Dyominov & Zadorozhny, 2005; Kinney, 2008; Ramanathan & Feng, 2009). Seven conventional air pollutants are responsible for the most serious threat to human health and welfare: sulfur dioxide, carbon monoxide, particulates, hydrocarbons, nitrogen oxides, photochemical oxidants, and lead (Cunningham & Cunningham, 2010). Out of these conventional air pollutants, this thesis is dedicated to nitrogen dioxide. From a theoretical perspective, nitrogen dioxide is a suitable proxy for a mixture of particles related to urban air pollution such as carbon oxides, particulate matter and soot (Fischer et al., 2000). The choice for NO_2 also has a practical reason: a decent amount of data from organizations such as Milieudefensie and GGD is available, most likely, because passive NO_2 monitors are relatively inexpensive to implement (Jerrett et al., 2005). Nitrogen oxide refers to both nitric monoxide (NO) and nitrogen dioxide (NO_2). These two molecules constantly undergo chemical interconversions in the atmosphere (Mayer, 1999). An indirect link between NO_x and climate change exists, notably the presence of nitrogen oxide promotes the formation of ozone in the troposphere and to a lesser extent in the lower stratosphere, where ozone has a positive radiative forcing (IPCC, 2013). Yet, nitrogen oxide emissions are directly related to other environmental problems, including photochemical smog, acid deposition, visibility reduction and of course health effects (Shorter et al., 2005). For instance, NO_x produces ground level ozone (smog) when it reacts with volatile organic compounds; a reaction that is enabled by heat and light.

1.2 Sources of nitrogen dioxide

Ahrens et al. (2012) estimate that almost one billion people in cities around the world are continuously exposed to unhealthy air pollution levels. In order to assess, and subsequently reduce air pollution in these urban areas, it is necessary to categorise the sources of emissions. Interestingly enough, in chemical terms the origin of nitrogen oxide is nitrogen. Nitrogen is a fundamental building block of life and is the most abundant element in the atmosphere: dry air contains 78% nitrogen by volume. However, nitrogen can generally not be absorbed by living organisms; first it needs to be converted into reactive compounds such as ammonia (NH_3), ammonium (NH_4^+), nitric oxide (NO), nitrogen dioxide (NO_2), nitric acid (HNO_3), nitrous oxide (N_2O) and nitrate (NO_3^-) (UNEP, 2007). This chemical reaction can take place due to anthropogenic sources or natural sources. In an effort to assess the relative importance of these two categories at a global scale, Delmas et al. (1997) estimate combustion of fossil fuel (~50%) and biomass burning (~20%) to be the dominant anthropogenic sources. Nitrogen oxides are formed from nitrogen and oxygen if fuel combustion reaches temperatures above 650°C (Cunningham & Cunningham, 2010). The remaining share of total emissions (~30%) originates from natural sources such as lightning and microbial activity in soils. In the soil, nitric oxide is produced through bacteria or water that oxidize nitrogen-containing compounds. It should be noted here that usage of fertilizers in agriculture is a human perturbation of this microbial activity. After nitrogen oxide has been formed through this variety of sources, in its turn, nitric oxide can be further oxidized in the atmosphere, which forms nitrogen dioxide. In the past 150 years, the anthropogenic contribution of transport, industry and agriculture to the formation of nitrogen oxides has increased by more than a factor ten (UNEP, 2007). This overall increase does not imply that there is an excess of reactive nitrogen around the world. On the contrary, developing countries generally have a shortage of reactive nitrogen, which has negative consequences for soil fertility and thus food production. A surplus of reactive nitrogen in industrialized nations is related to other environmental and health problems including eutrophication and smog.

1.3 Nitrogen dioxide emissions from traffic

The primary contributor to nitrogen oxide formation in urban environments is road traffic (Fenger, 1999). The obvious fact that road traffic is in the immediate surroundings of urban citizens results in high levels of exposure. For instance, predictions for annual mean NO_2 concentrations in London have indicated that exceedance of EU air quality standards will mostly be restricted to the near-road environment (Carslaw & Beevers, 2005). The underlying reason is that NO_x has a short atmospheric lifetime, which causes ambient air pollution with respect to NO_x to show high spatial and temporal variability (Lewné et al., 2004). The temporal variability is clearly reflected in a study into the annual, weekly and diurnal cycles of NO and NO_2 in Stuttgart, southern Germany in the period 1981-1993 (Mayer, 1999). His research shows two peaks in NO and NO_2 concentration each day that coincide with morning and evening rush hours. Another observation is that NO shows stronger fluctuation than NO_2 on all timescales, as NO_2 has a longer lifespan compared to the more reactive gas NO. Kurtenbach et al. (2001) found a rather precise lifetime of NO_2 using measurements of NO_2 concentration in a tunnel between Düsseldorf and Wuppertall. From the decay of NO_2 after the engines were switched off, they calculated that NO_2 has a lifetime of 51 ± 3min. Obviously, this was a specific result for this particular tunnel due to a certain continuous dilution of tunnel air, but it characterizes the short life time of NO_2 in general.

Nitrogen oxides emitted from road traffic are predominantly in the form of NO, however, smaller quantities of NO_2 can also be released. The NO_2/NO_x ratio is of interest, because NO_2 is a toxic molecule, and also promotes the formation of ozone (Ban-Weiss et al., 2008). If diesel engines are compared with gasoline engines on this ratio, then diesel engines have a higher NO_2/NO_x ratio than gasoline engines (Jimenez et al., 2000). For New York City, researchers comparing different types of mass transit buses (Shorter et al., 2005) find that diesel and compressed natural gas buses emitted approximately the same amount of NO_x, whereas hybrid electric buses had only one-half of the NO_x emissions. All of the buses had a NO_2/NO_x ratio of less than 10%. These two studies provide evidence that the fuel type of a vehicle is a crucial determinant for its NO_x emission.

Chapter 2: Analyzing air pollution exposure

Knowledge about NO_2 emissions and sources enables the development of air pollution exposure models with a theoretical basis. The role of exposure models is to gain deeper insight into how spatial variables such as trees, traffic intensity and distance to road explain the spatial distribution of air pollution. Improved exposure models lead to better health risk assessment and more accurate monitoring of air quality standards (Briggs et al., 1997). Additionally, improved models contribute to the evaluation of government policies with respect to emitters such as transport and industry. For these reasons, policy-makers, NGOs and public health organizations are increasingly interested in exposure models.

2.1 Types of air pollution exposure models

Four types of exposure models are often employed in urban air pollution literature. Increasing in complexity, these models are proximity models (e.g. Janssen et al., 2001), interpolation models (e.g. Pikhart et al., 2001), land use regression models (e.g. Briggs et al., 1997), and dispersion models (e.g. Hruba et al., 2001).These types of models arrive at predicted values through a different approach. This thesis employs a land use regression model, but it is instructive to see how other exposure models produce predicted values first.

Proximity models use the distance from a certain location to a pollution source to differentiate exposure rates. Proximity models are largely based on Tobler's (1970) first law of geography: all things are related, but near things are more strongly related than distant ones. These models provide an exploratory analysis on the impact of an emission source on a certain location, but fail to include parameters that affect the real dispersion.

Interpolation models start with measurements from monitoring stations. Through geostatistical techniques the interpolation models create a map for the entire urban area, including the sites that do not have a monitoring station. One of the most common methods is 'kriging' (Jerrett et al., 2001). The main advantage of this method over other interpolation methods is the inclusion of standard errors that quantify the uncertainty of interpolated exposure values. This information indicates the reliability of the predicted exposure values. The problem is that air pollution patterns are often highly complex with steep gradients and localized peaks (Briggs, 2005). Therefore, a high number of measurement stations and a uniform distribution of measurement stations across the urban area is required for interpolation models to be meaningful.

Dispersion models incorporate both spatial and temporal variations of air pollution, as dispersion models simulate the process of dispersion. Temporal variation results from variation in source amplitude (e.g. traffic intensity), wind direction and wind velocity. In order to capture these variations in an air pollution map, dispersion models work with Gaussian plume equations (Bellander et al., 2001). It should be noted that dispersion models only provide estimates based on known emission sources in the locality. Yet, an important part of the total concentrations is not locally derived (Briggs, 2005). This detail is more of an issue for developing countries than it is for Amsterdam, since almost all emission sources have been mapped in the Netherlands. Data requirements are relatively heavy and comprise mostly data about the emission sources and factors affecting their dispersion, hence for instance traffic volume, emission from point sources, meteorology and topography. Although this makes the dispersion models more expensive to put into practice, their ultimate results are often the most reliable and meaningful. The emphasis on the process how particles pollute the atmosphere makes dispersion models realistic.

In this chapter, a land use regression model is developed. The main reason for using this class of exposure models is that land use regression models are characterised by relatively reliable outcomes and relatively low data requirements.

2.2 About land use regression models

Land use regression models do not only rely on monitored data, but they also include explanatory variables to predict air pollution exposure values. In other words, the assumption is that surrounding land use, building density and traffic characteristics can explain air pollution patterns. Data about these surrounding characteristics is widely available for Amsterdam. The usage of monitored data is twofold in land use regression models, whereas it is one-fold in interpolation models. Notably, in land use regression models the monitored data is first used to calibrate the least-squares multiple regression function that consists of the explanatory variables. Subsequently, the monitored data validates the regression function produced by a statistical software package (e.g. SPSS). The results from land use regression models are robust over time in a sense that with appropriate recalibration, the models can be applied for different averaging periods, for instance weeks, months or years (Briggs et al., 2000). However, transferability over space is merely feasible for similar geographic urban areas with the same land use and traffic characteristics. Thus, transferability remains an issue for most other urban areas as the differences are too significant (Elliott et al., 2000). The data requirements in terms of different variables for land use regression models are higher than for interpolation models, since not only monitoring measurements are needed, but also explanatory variables.

Model development in land use regression models commences with the selection of measurement stations. Measurement stations are either part of a routine network (e.g. GGD network) that continuously measures concentrations levels or of a network that has been specifically set up for model development (so-called *purpose-designed monitoring*). The number of measurement stations varies widely across different studies. Hoek et al. (2008) recommend a number between 40 and 80 for land use regression models with respect to an urban area like Amsterdam. Distribution of measurement stations is often determined by the explanatory variables. The rationale behind this distribution is to capture the extremes in explanatory variables in order to record the extremes in air pollution exposure as well. On the other hand, Kanaroglou et al. (2005) introduced a more systematic method for the selection of monitoring sites. They used an algorithm that assigns relatively more measurement stations to areas where the expected air pollution variability is higher and where more people live. Explanatory variables that are frequently used in models are traffic variables, population or housing density, land use, meteorology, altitude and topography (Hoek et al., 2008).

2.3 Data

This study was performed with measurement data from the GGD Amsterdam – a public health agency from the municipality. Helmink et al. (2013) wrote a report "GGD Amsterdam, Air pollution Amsterdam 2012". The GGD dataset involved yearly averages of NO_2 concentration in 2012 and was therewith attractive due to its recent nature. Another reason to select the GGD data set is its measurement density: with 102 measurement stations it is more than the 40-80 measurement stations recommended by Hoek et al. (2008) for an urban area similar to Amsterdam. At 12 measurement sites the GGD employs chemiluminescence. Chemiluminescence is the technique that is prescribed by the EU to measure NO_2. This technique involves that the measurement device alternates between two states: the first state samples ambient air directly and measures the NO concentration, and the second state samples the sum of NO and NO_2 by converting NO_2 to NO. This conversion is initiated by letting the ambient air pass over a catalyst such as gold or molybdenum oxide (Dunlea et al., 2007, p. 2692). The subsequent NO indirect measurement is based on the chemiluminiscent reaction of NO with O_3, which forms electronically excited NO_2. This NO_2 fluoresces at visible and near infrared wavelengths that can be relatively easily detected. Lastly, the NO_2 concentration is calculated by taking the difference between the second state and the first state.

For the other 92 measurement stations the GGD uses so-called Palmes tubes for their routinely performed NO_2 monitoring programme. A Palmes tube is a low-cost passive sampling device. Palmes et al. (1976) were the first to describe this method and by now the method has been validated and compared to continuous measurements such as chemiluminescence (Stevenson et al., 2001). Figure 4 shows the locations and average NO_2 value at the measurement stations in 2012.

Other sources were used as input to map potential predictors. Predictors included distance to main road, traffic characteristics, density of main road in vicinity, density of green space, density of water and density of buildings.

All predictors related to roads and traffic characteristics were derived from the National Cooperation Programme Air Quality (NSL).[1] The NSL has an extensive dataset on traffic characteristics, such as volume and composition. The NSL is a collective programme from the national government and local municipalities to improve air quality for the purpose of public health. The calculations from their *Monitoringstool* form the legally binding test of the air quality in the Netherlands.

All other predictors are related to land use. These predictors find their origin in data from the Central Bureau for Statistics (CBS, 2012a), but were reclassified to be employable in a regression model.

[1] For more information, please visit http://www.infomil.nl/onderwerpen/klimaat-lucht/luchtkwaliteit/rekenen-meten/nsl-rekentool/

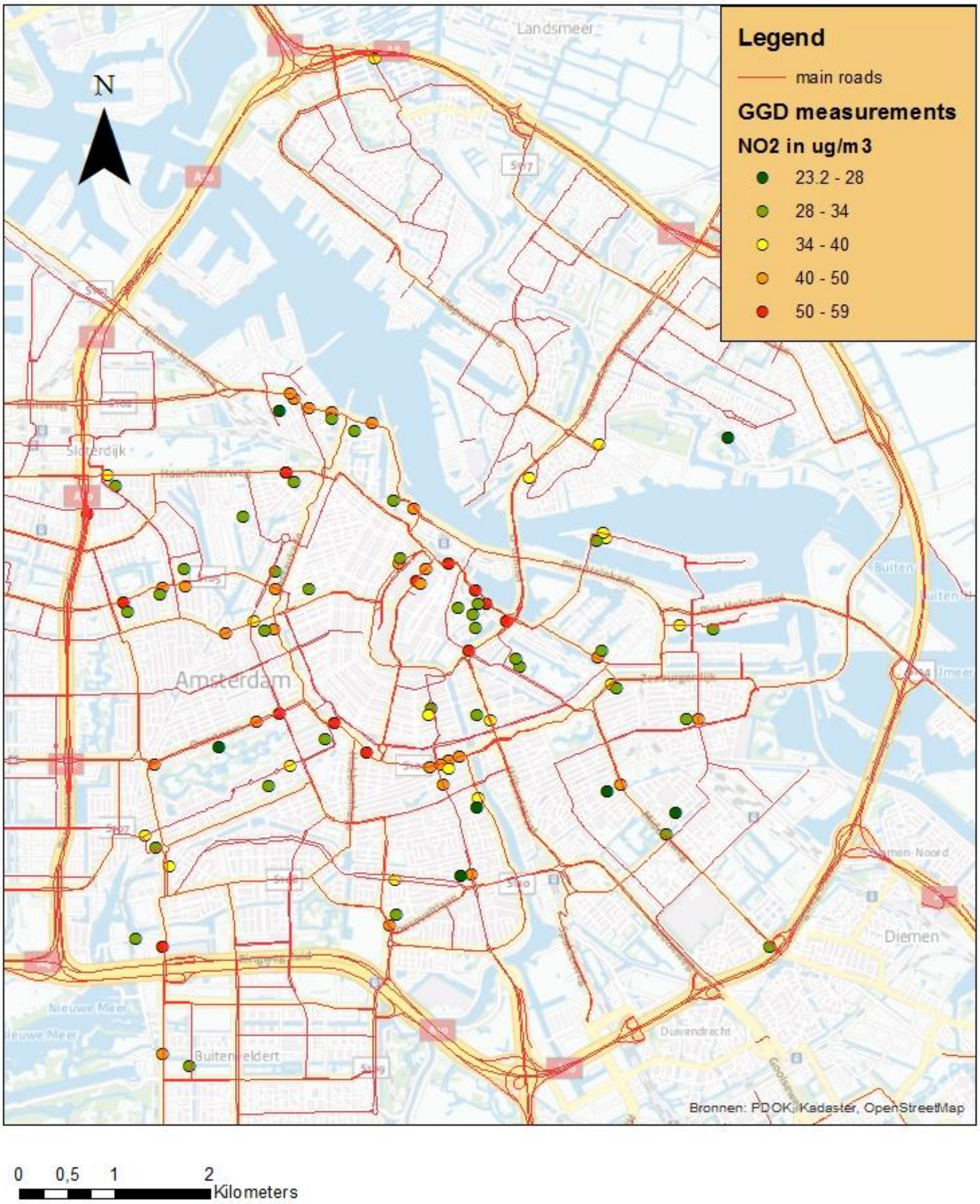


Figure 4: Average NO_2 concentration in μg/m^3 for the GGD measurement stations in Amsterdam over the year 2012. Due to the low measurement station density outside of the ring highway A10, the model focuses on the area bounded by the ring highway.

2.4 Development of a regression model

The spatial analysis was carried out in ArcMap 10.1, which is a geospatial processing programme. The geodatabase contained four main sets of data:

- Road traffic data from NSL
- Land use data from CBS
- Monitored NO_2 concentrations from GGD
- Background map *PDOK BRT Achtergrond* from ArcGIS online

The spatial analysis resulted in values for the NO_2 concentration and corresponding values for the predictors. The statistics were exported to SPSS Statistics 20 to conduct a multiple regression analysis, after which the regression function was imported into ArcMap again to visualize it. The process is depicted in the flow diagram of Figure 5.

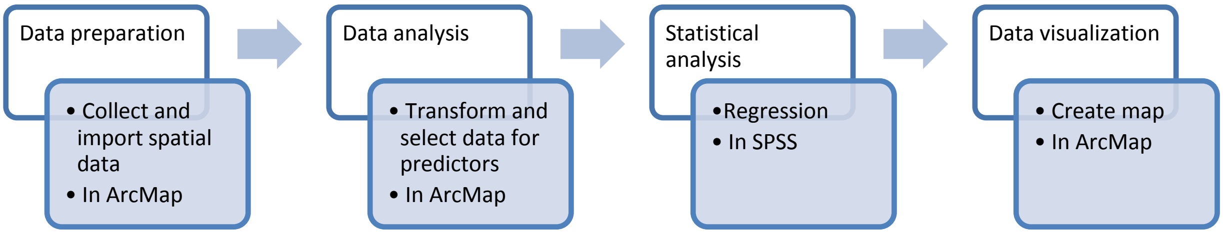


Figure 5: Flow diagram of the process from raw data to concentration map.

1) Data preparation

To be able to work in ArcMap, data on air pollution had to be collected and imported. The data from a GGD report on air pollution in Amsterdam from Helmink et al. (2013) formed the basis of the analysis. However, the data was scattered throughout that report and the values had to be collected from different tables. Rearranging the data and using the X,Y coordinates ensured the NO_2 values were mapped accurately. RD_new is the projected coordinate system that was used for all layers.

The raw land use data consisted of 16 different categories. In order to transform this abundance of categories into a useful smaller set consisting of five categories, the reclassification tool was used (*see Appendix I*). This newly obtained land use map was then reclassified again giving a value 1 to Green/Park and a value 0 to all other categories, so that the categories were readily employable in the next step.

2) Data analysis

To analyse the degree to which predictors influence the NO_2 concentration, different radii around the measurement stations were used. The values for these radii were taken to reflect values commonly found in literature on air pollution in Amsterdam (Dijkema, 2011; Brauer et al., 2003; Briggs et al., 1997). The following description of the data analysis steps is certainly not exhaustive, yet provides an overview of the main tools that were applied to develop a land use regression model. The first tool is Focal Statistics, which calculates the average value of the cells in a certain radius. Since Green/Park and Water had been reclassified into values of 1 and 0 in the previous step, the Focal

Statistics tool calculated in essence the ratio of Green/Park to other land uses within a certain radius. For water a radius of 75m, 100m and 125m was calculated, whereas Green/Park ratio was computed for a radius of 200m, 250m, 300m and 500m. Note that the value in the predictor's name in figure 6, for instance green_250m, refers to the radius. Having obtained all these different maps, the analysis proceeded by coupling the spatial information of the predictors to the measurement station locations by means of the Extract Multi Values to Points tool.

	N	Minimum	Maximum	Mean	Std. Deviation
green_200m	104	.00	.70	.06	.13
green_250m	104	.00	.71	.07	.13
green_300m	104	.00	.64	.07	.12
green_500m	104	.00	.41	.07	.10
INT_LV	104	.00	91227	9626.57	9903.94
INT_MV	104	.00	3704	266.48	377.63
INT_ZV	104	.00	2710	153.79	297.52
NEAR_DIST	104	.00	289.41	44.37	55.16
NO2__ug_m3	**104**	**23.20**	**59.10**	**37.92**	**9.04**
RoadBuf_30	104	.00	1.00	.51	.45
water_100m	104	.00	.61	.09	.12
water_125m	104	.00	.48	.10	.12
water_75m	104	.00	.76	.09	.13
Valid N (listwise)	104				

Figure 6: Descriptive statistics for the predictors and the response variable (in bold) in alphabetic order. The predictors related to land use have been given a green or blue colour, whereas the predictors related to traffic have been marked grey.

The NSL data on traffic was bundled in a layer called *wegvakken_2012* and enclosed data on the number of light/middle/heavy traffic movements and maximum speed among others of the main roads in Amsterdam. The tool Near produced a column called *NEAR_DIST* within the attribute table of the measurement stations (*NO2_GGD_2012*) that indicated the distance to the nearest *wegvakken_2012* line feature, hence the nearest main road. This distance was used to find an appropriate buffer size of the main roads: a buffer size that includes the orange and red points from Figure 4, but excludes the green and yellow points. The result was a buffer size of 30m. After transforming this buffer into a raster and reclassifying its values to 1 (buffer area) and 0 (non-buffer area), the Focal Statistics tool calculated the percentage of buffer area for each raster point in a radius of 30m. This layer was named RoadBuf_30. It should be noted that this model assumes that the effects of the road are tenable until 30m (buffer) + 30m (radius focal statistics). Hence, the RoadBuf_30m values correspond to 60m in total. The data concerning the light/middle/heavy traffic movement (*INT_LV, INT_MV, INT_ZV*) was added to the attribute table of *NO2_GGD_2012* through the option Joins and Relates.

3) Statistical analysis

In SPSS a linear multiple regression analysis was performed to examine how the predictors explain the variance in NO_2 concentration. Since forward, backward and stepwise testing resulted in the same model, model selection was a straightforward exercise.

4) Data visualization

The multiple regression analysis performed in SPSS resulted in a regression function. The unstandardised coefficients indicate the value with which each predictor needed to be multiplied for an optimal prediction. The unstandardised coefficients formed the input for the tool Map Algebra that computed an air pollution exposure map by multiplying each predictor with its unstandardised coefficient and adding a constant for the entire area.

2.5 Results: concentration map

Out of the 12 predictors that were entered into the stepwise regression analysis only one predictor was found to be significant: RoadBuf_30. The variable NEAR_DIST also showed a significant Pearson correlation with the NO_2 concentration, but due to high multicollinearity between RoadBuf_30 and NEAR_DIST, the latter was no longer significant in a regression model that included both predictors. All other excluded predictors showed significance levels of 0.157 and higher. This is the significance value of that predictor, if that predictor is added to the model as second explanatory variable. Additionally, the Pearson correlations of the other excluded predictors with the response variable was small with an absolute value smaller than 0.118. The regression output generated by SPSS can be found in *Appendix II*. The R^2 – a measure of model fit – is 0.538. The final regression function is:

$$NO_2\ concentration = 30.355 + 14.980 * RoadBuf\_30$$

Here the constant 30.355 is interpreted as the background concentration and the variable RoadBuf_30, which measures the density of main roads in the vicinity, adds to that background concentration. Using this regression function in the tool Map Algebra resulted in the concentration map from Figure 7.

2.6 Robustness of model

The robustness of the model was assessed with a second data set on average NO_2 concentration in Amsterdam in 2012. The data originated from 17 measurement stations deployed by Milieudefensie. Through a comparison of their measured value with the predicted value from the model, a R_2 was calculated as follows:

$$R^2 = \frac{sum\ of\ squares\ due\ to\ regression}{sum\ of\ squares\ about\ the\ mean} = \frac{\sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} = \frac{787}{975 + 787} = 0.45$$

For the data and the precise calculation *see Appendix III*. Due to the small reduction in R^2, it is concluded that the model is robust.

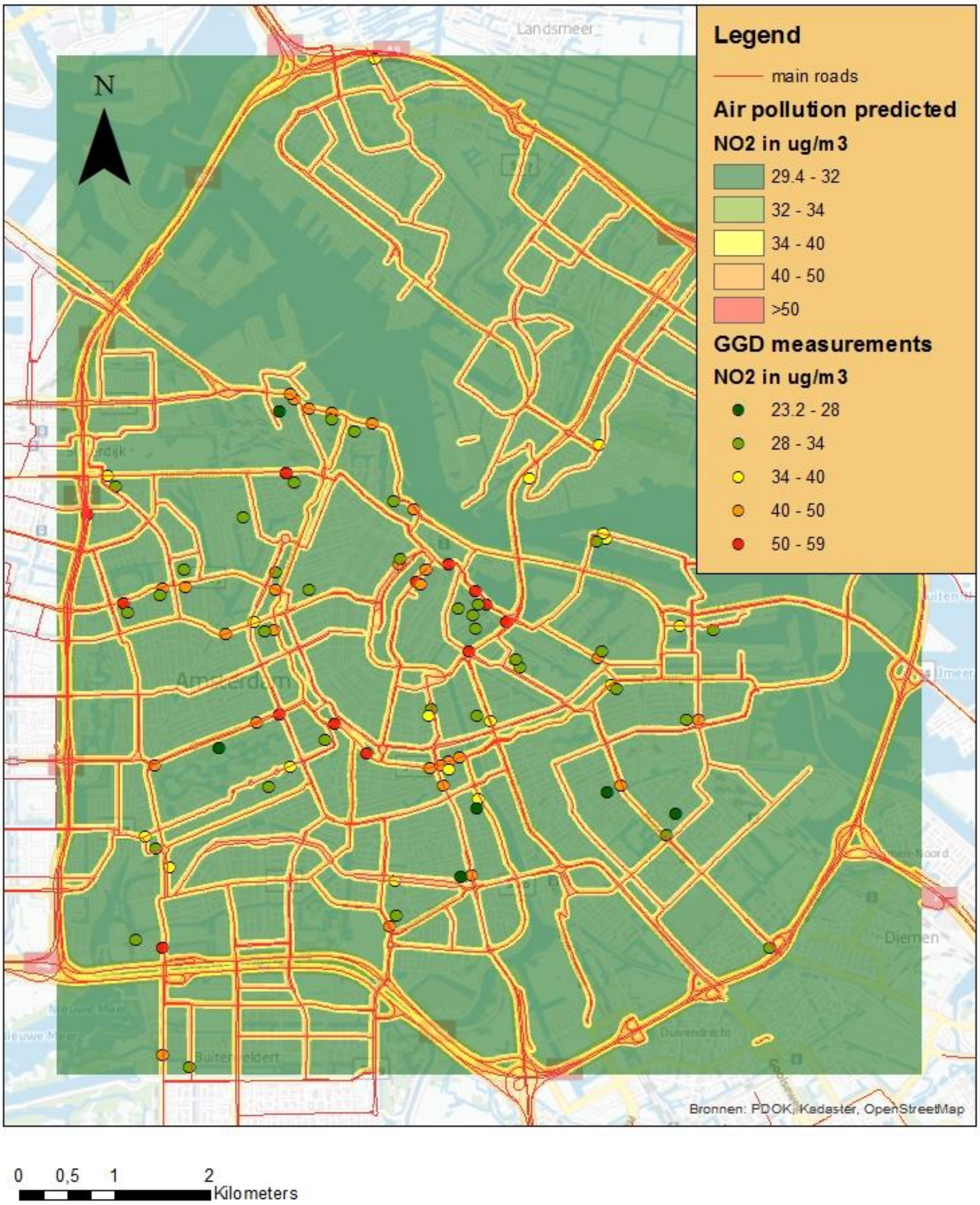


Figure 7: NO_2 concentration map for Amsterdam based on the GGD measurements over 2012. As RoadBuf_30 is the only predictor, the maps shows high concentrations at the midpoints of the main roads. From 60 meter and further from the main roads, the model predicts a background concentration of 30.4 µg/m^3.

Chapter 3: Reviewing the influence of socioeconomic status on the health impact from air pollution exposure

This chapter will outline the degree to which air pollution has an impact on health. After this general relationship has been discussed, the impact of the moderating variable socioeconomic status will be examined to see if it has an influence on the general relationship between air pollution and health impact. The relations are depicted schematically in Figure 8. It should be noted that this chapter is devoted to the health impact of air pollution at large instead of only NO_2.

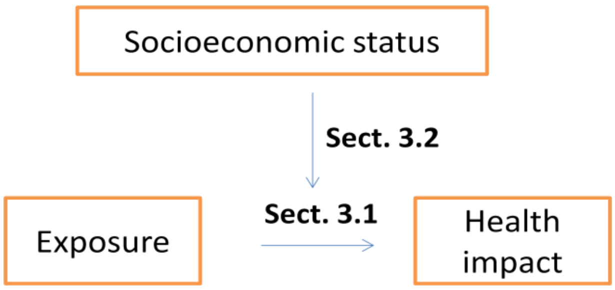


Figure 8: How section 3.2 describes the moderating variable socioeconomic status with respect to the relation between exposure and health impact.

3.1 Health impact of air pollution

Recently, the World Health Organization released a report on the health impact from air pollution. It concluded that air pollution is the single biggest environmental health risk linked to 7 million deaths per year worldwide (WHO, 2014). This report took into account both household (indoor) sources as wood/coal stoves and ambient (outdoor) sources as traffic emission and coal-burning. The number of deaths in the European Region totalled almost 600,000, of which 482,000 are attributable to ambient sources and 117,000 to household air pollution.

Air pollution contributes to both mortality (death rate) and morbidity (illness rate). As for morbidity, air pollution has been linked to cardiovascular illnesses and respiratory illnesses such as asthma (Brunekreef & Holgate, 2002; Kuenzli et al., 2000; Pope & Dockery, 2006). An extensive body of literature treats the association between these illnesses and air pollution. In the past one and a half decade, two trends have become visible in the literature. Firstly, more research has been conducted on health effects of long-term exposure (cf. short-term) to air pollution (e.g. Beelen et al., 2008; Gehring et al. 2006). At the same time, traffic received higher priority as source of air pollution (Bellander et al., 2001; Kurtenbach et al. 2001). One study in particular is highly relevant for this thesis to discuss in more depth: a study by Dijkema et al. (2011) that investigates the relation between long-term exposure to traffic related air pollution and cardiopulmonary hospital admissions. Cardiopulmonary diseases involve diseases related to the heart or the lungs. The study used hospital admission data (2001-2004) and population data to evaluate the association between air pollution and health impact at postcode area level in the western part of the Netherlands. The reason for picking this study to discuss at greater length is fourfold. Firstly, it is conducted in the West of the Netherlands and includes the city of Amsterdam. Therefore, it is geographically relevant to this thesis. Secondly, due to its ecological design – usage of existing data sets – their research could evaluate a large number of people (4.04 million) and a large number of diseases. That number is double to tenfold the number found in other studies (e.g. Andersen et al., 2011; Lin et al., 2002), which use a case control design. Thirdly, Dijkema et al. (2011) wield modelled NO_2 concentrations based on predictors green space, water, distance to nearest main road and traffic volume to estimate exposure levels, whereas many other studies use merely proximity to traffic. Brauer et al. (2003) showed that modelled NO_2 concentrations are probably a better estimator of exposure than traffic indicators.

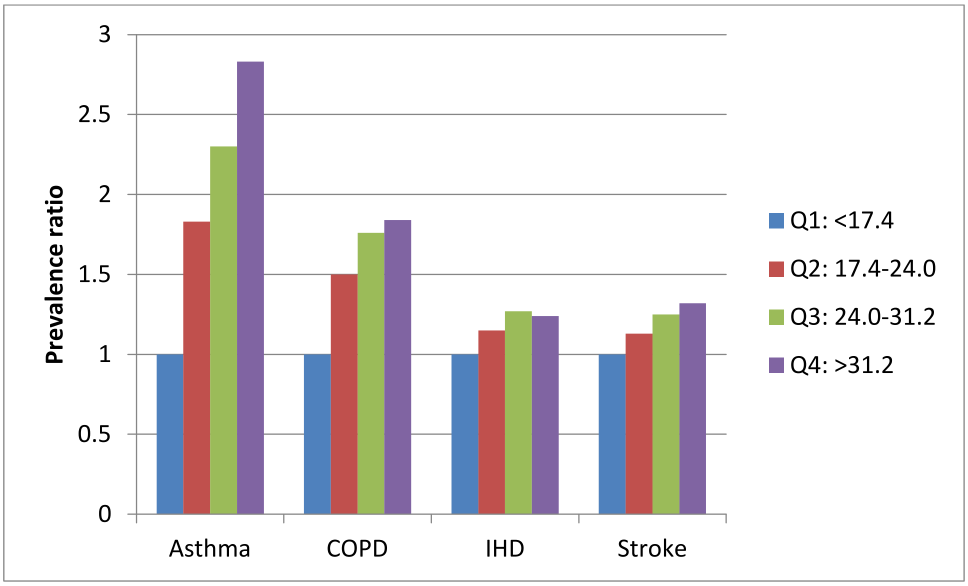


Figure 9: Association between NO_2 concentration and hospital admissions. The four quartiles are based on exposure in µg/m^3 NO_2. The prevalence ratio indicates the hospital admissions with reference to the lowest quartile (reference point = 1). This figure is based on data from Dijkema et al. (2011, p. 49).

The associations were analysed for all asthma, chronic pulmonary obstructive disease (COPD), ischemic heart disease (IHD) and stroke. Examining the hospital admissions prevalence ratios in Figure 9 for the lowest exposure quartile and the highest, a remarkably high prevalence ratio is found for asthma of 2.8. Additionally, COPD and stroke show high ratios of 1.6 and 1.3, respectively. It is crucial to note that increased prevalence ratios are also observed for concentration below the EU limit value for NO_2 concentrations of 40 µg/m^3, whereas these limit values are supposedly based on health impact.

Although the associated health effects relate to more air pollutants than purely the NO_2 concentrations, NO_2 is the most heavily legislated air pollutant in the EU (Briggs, 2005). The origin from the EU limit values lies in the WHO guideline for NO_2, even though the WHO clearly indicated that this value is mostly based on indoor studies and a well established limit value still needs to be found (WHO, 2006).

3.2 Socioeconomic status as moderating variable

In general, the literature describes an inverse relation between socioeconomic status and health impact of air pollution. For NO_2 there is some suggestion that people with a lower level of socioeconomic status based on income have an increased risk of cardiovascular mortality (Villeneuve et al., 2003). For instance, increased mortality was associated with air pollution and lower socioeconomic status in a citywide model in intra-urban zones in specific for the city of Hamilton, Canada (Jerrett et al., 2004). Evans and Kantrowitz (2002) argued that the ubiquitous socioeconomic status-health gradient is partly caused by different exposure to environmental risk such as exposure to ambient air pollutants. Another study found that predominantly subjects over 65 years old are at higher risk of mortality associated with air pollution, whereas associations between air pollutants and mortality in children under 5 years of age were not significant (Gouveia & Fletcher, 2000). This finding is in accordance with a study in Shanghai, which concluded that the effect estimates for mortality in the age groups 5-44 years of age and 45-64 years of age did not differ. Yet, the effect estimates of air pollutants for the group 65 years of age and older were significant and 2-5 times higher than among the previous two age groups (Kan et al., 2008). Other studies also conclude that the association does not hold as strongly or is non-existent for children until 14 years of age (Lin et al., 2002; Wilkinson et al., 1999). In conclusion, income and age are the most important moderating socioeconomic variables on the health impact of air pollution. Income is taken as indicator for socioeconomic status and the lower income the higher vulnerability for air pollution. For age holds that vulnerability for high concentration levels increases rapidly from 65 years of age onwards.

Chapter 4: Assessing air pollution impact

In Chapter 3 it was concluded that income and age are the most important moderating variables with respect to the health impact of air pollution. In this chapter that knowledge will be applied to assess the air pollution impact in Amsterdam.

4.1 Data and methods

Although the most important moderating variables – income and age – have been identified, exact quantification of this relation is outside the scope of this thesis. Borrowing the result of other researchers is not an option, since the literature provides different quantifications for different urban areas. The quantifications are also dependent on the air pollutants and illnesses examined (e.g. Kan et al., 2008; Gouveai & Fletcher, 2000; Pope 3rd et al., 1995).

For that reason, it is assumed that income and the number of citizens who are 65 years or older are linearly related to the impact of air pollution and that both carry the same weight. The number of citizens who are 65 years or older is calculated from the population density and the corresponding percentage of the total population that is 65 years or older. From here on the population that is 65 years or older will be referred to as elderly. It was decided to focus on this age group, since several scholars found that predominantly the elderly are at higher risk of mortality associated with air pollution (Gouveia & Fletcher, 2000; Kan et al., 2008). Hence, as a formula:

$$air\ pollution\ impact = exposure\ x\ vulnerability$$

$$= predicted\ NO_2\ concentration\ x\ \frac{number\ of\ inhabitants\ x\ \%\ elderly}{mean\ income}$$

The number of inhabitants came from a data set on the number of housing units per 100 meter square grid for the year 2008 from PBL Netherlands Assessment Agency. The demographic data about the % elderly on January 1, 2011 was obtained from the Central Bureau for Statistics (CBS, 2012b). It was aggregated on the scale of neighbourhoods (*buurten*). For income per district (*stadsdeel*) in 2011, Data from Bureau Research and Statistics Amsterdam was used in this calculation.

The reason for using different sources for the different variables is that for every variable the data was used from the source that aggregated it at the smallest scale. For instance, the CBS also had data on total number of inhabitants, but its scale was much coarser.

4.2 Results: impact map

The impact map is the result of four maps, of which the concentration map has already been discussed in section 2.5. Conceptually, the result was derived from putting the four layers on top of each other. The layers are linked through a multiplication of the variables that the layers represent. The three other layers can be found in appendix IV – VI. The final result of this multiplication is displayed here in Figure 10.

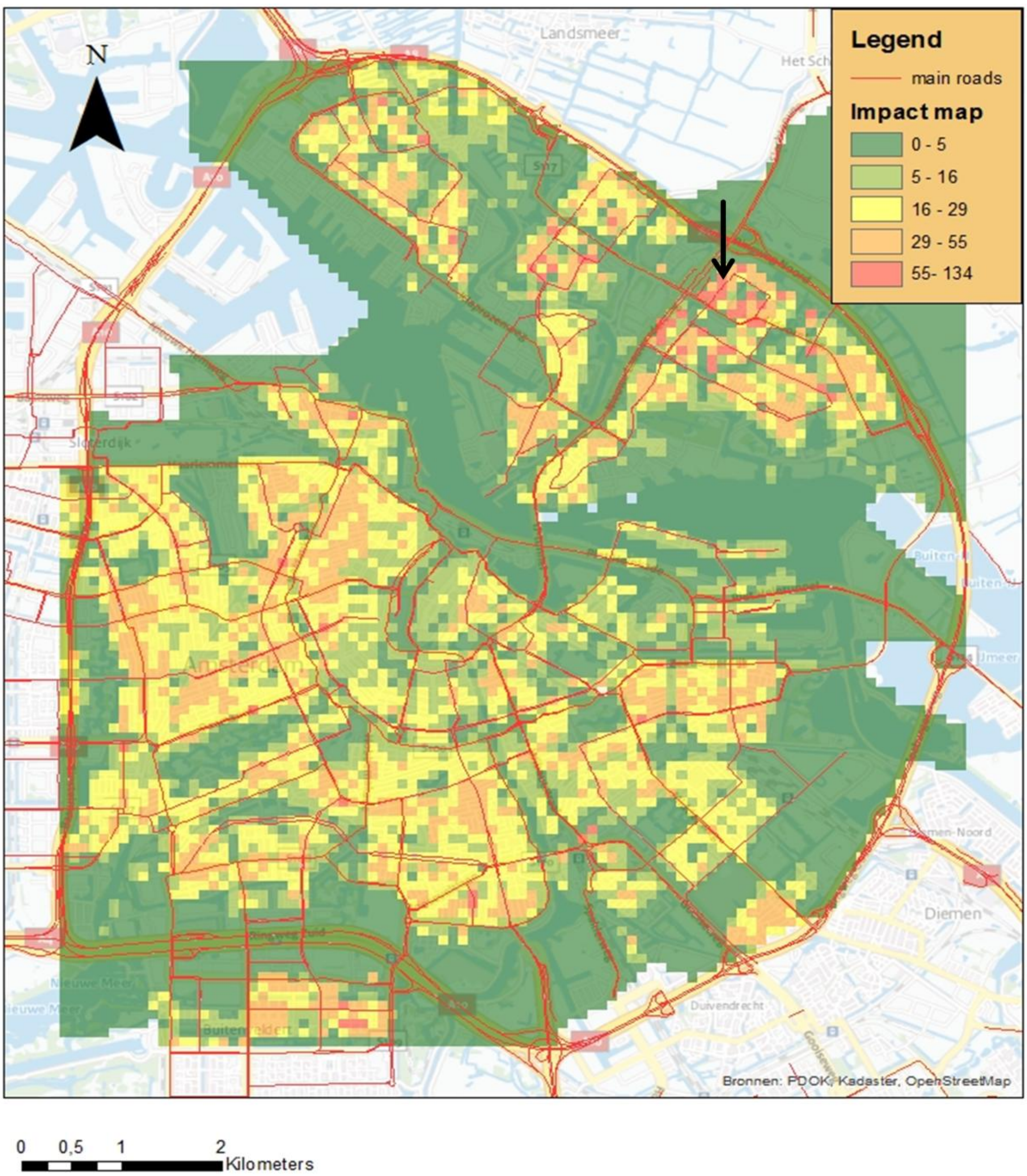


Figure 10: The impact map of NO_2 concentration in Amsterdam. The unit of this map is no longer meaningful. The geographic relative differences matters more. It is interesting to note that the largest health impact of air pollution taking into account income and number of elderly occurs in district Noord. After some desk research with Google maps, it is interesting to note that the arrow that points at one of the red pixels in Noord indicates an elderly home called *Evean Korthagenhuis* that happens to be located close to main roads.

Chapter 5: Evaluating different policy measures aimed at reducing air pollution

Now that a clear image has been sketched of the exposure, vulnerability and impact of air pollution in Amsterdam, it is time to evaluate different policy measures. Policy measures are defined as actions taken by administrative executive branches of the state with respect to air pollution in Amsterdam. Policy measures need to be consistent with law and institutional customs. This chapter starts by describing the current policy (measures) in place. Subsequently, a view is presented on the ideal policy measures given the impact map from Chapter 4. Lastly, the difference between the current policy measures and the ideal policy measures provide an evaluation of current policy measures and an indication of the needed interventions over time.

5.1 Current regulation

Since August 1, 2009 Amsterdam improves the air quality mainly through the National Cooperation Programme Air Quality (NSL) (Amsterdam.nl, 2014a). The NSL is a cooperation programme from the national government and local governments to improve the air quality in the Netherlands. Regulation and legislation with respect to air quality can be found on two different levels: European regulation and national regulation.

5.1.1 European regulation

The European Commission proposes the standards for NO_2 concentration, after which the legislative powers of the EU – the Council and the European Parliament – adopted it in the Directive 2008/50/EC. As discussed in the introduction, the limit value for NO_2 as set by the European Commission is 40 $\mu g/m^3$ from 2015 onwards. The limit value relates to the average of a calendar year (European Commission, 2008, p. 30). At the same time, one hour averages may not exceed 200 $\mu g/m^3$. The limit values are said to be health-based standards, yet, section 3.1 has shown how health-based standards would be much stricter. These limit values entered into force on January 1, 2010, but Member States could apply for an extension of up to five years. For this reason, the Netherlands have to comply to these limit values only from January 1, 2015 onwards.

5.1.2 National regulation

Dutch regulations are based on European regulations. Dutch regulations are captured in title 5.2 of the law for environmental management (Overheid.nl, 2014). As title 5.2 deals with air quality, title 5.2 is informally known as the Air Quality Law. Title 5.2 forms the legal basis for the NSL. Title 5.2 stipulates general provisions, plans, national programme and other programmes, execution of competences or application of legal provisions, assessment of air quality, and enforcement and international cooperation.

5.2 Current policy measures at work in Amsterdam

Amsterdam currently employs several policy instruments that aim at reducing air pollution in the city (Amsterdam.nl, 2014b). The instruments are inspired by non-compliance of the EU standards. The GGD Amsterdam also plays a role in pushing for more stringent legislation, but that is from a public health perspective. The two main pillars of Amsterdam's set of policy measures are exclusion of the most polluting lorries in a so-called Environmental zone and subsidies for purchasing 'clean' vehicles for frequent road users.

5.2.1 Subsidies for greening vehicles

One of the main pillars of the current policy is to subsidize clean vehicles for frequent road users, such as taxis, vans, and lorries. Clean vehicles may refer to electric vehicles, but also to vehicles with a diesel engine that meets the Euro 6 standard. The European Commission's proposal on the Euro 6 standard for heavy-duty vehicles was adopted to reduce their emissions in 2009. The Euro 6 standard refers to emission standards with respect to air pollutants such as CO, NO_x and PM. The subsidies for meeting the Euro 6 standard are lower than for electric vehicles though. In addition to vehicles, also funds for greening canal cruise vessels existed from 2011 till 2014. From 2014 onwards the funds are used for entrepreneurs who switch to an electric vessel. As a rule, the subsidy that an applicant receives is dependent on the type of vehicle and the emissions of that vehicle. Only applicants whose business is located in Amsterdam or one the surrounding municipalities and who drive in the Environmental Zone at least five times per week are eligible for a subsidy. Obviously, the lower the emissions of the new vehicle, the higher the subsidy that is granted. Some of the subsidies are supplemented by the national government with a similar amount.

In order to illustrate the size of the subsidies involved, some examples will be provided. For instance, frequent drivers for business purposes can receive €5000 for an electric car. A taxi company receives the exact same amount for an electric taxi, yet in that case the national government supplements another €5000. If a taxi company purchases a hybrid gasoline taxi, it receives €1250 of financial support both from the municipality and the national government. For an electric lorry, the city of Amsterdam finances €40,000 of the total cost.

Furthermore, the municipality subsidizes charging infrastructure for electric vehicles. For a charging point on public space the maximum is €1000, whereas on private space the maximum is €500. A maximum of 50% of the total costs is refunded. In total, the city of Amsterdam has allocated 17 million euro to spend on greening vehicles in the period 2011-2015.

5.2.2 Environmental zone

The second important pillar of the Amsterdam air quality policy is the Environmental Zone. The start of the Environmental zone was in 2008. The policy was adopted in order to avert the most polluting lorries from entering this central zone. From July 1, 2013, only lorries with a Euro 4 or higher diesel engine and lorries without a diesel engine have access to the Environmental zone. The border of this area can be seen in Figure 11 on the next page.

5.2.3 Zoning of housing for vulnerable citizens

On top of the Dutch regulations, Amsterdam has added a local guideline on the zoning of housing for vulnerable citizens (Amsterdam.nl, 2014c). It states that no new facilities can be realized for elderly or citizens with a vulnerable health and for education or day-care for minors in Amsterdam. The national regulation only applies to highways and provincial roads, yet the guideline from Amsterdam also offers protection against air pollution to vulnerable groups near busy intraurban roads.

5.2.4 Other policy measures

Lastly, some measures have been implemented that are smaller in impact, but worthwhile to mention. Firstly, the timeslots for lorries to load and unload have been widened in order to improve the traffic flow of the lorries. Hence, the time a lorry pollutes the Amsterdam area is essentially shortened, and thus its total emissions. Secondly, the city of Amsterdam stimulates bundled delivery of goods through an urban distribution network. The logistic activities have been outsourced to a commercial player, but the municipality promotes and subsidizes it. Urban distribution involves environmentally friendly lorries – some of which electric – that deliver to different shops and firms.

Figure 11: The border of the Environmental Zone in May 2014. Effectively, the Environmental zone encompasses practically the entire area within the ring highway A10 and to the south of the IJ. Note that the inlets such as De Omval comprise industrial areas.

Source: http://amsterdam-maps.bma-collective.com/embed/milieuzone/

5.3 Ideal policy measures

The explanation why air pollution can hardly be solved by the citizens themselves, and thus why government intervention is needed, comes from economic theory. According to economic theory that is called the 'tragedy of the commons', individuals can act rationally and independently in their self-interest, but at the same time act contrary to the whole group's (to which the individuals belong) long-term interest by depleting a common resource (Hardin, 1968). The atmosphere is such a 'commons'. The rational actor finds that the cost of reducing air pollution is higher than the cost of the air pollution caused by himself onto himself. Yet, the cost of reducing pollution is lower than the cost of the pollution caused by all rational actors onto this one individual. This economic theory legitimizes government intervention by coercive law (e.g. Environmental zone) or taxing/subsidizing devices (e.g. subsidy for electric vehicles) that trigger even the self-interested individual to reduce pollution.

in the first place, the ideal set of policy measures targets the yearly average of NO_2 concentrations and reduces it to its limit value of 40 $\mu g/m^3$. In the second place, from a public health perspective it aims at minimizing the health impact of the NO_2 concentration by protection of vulnerable groups.

With respect to public health, Giles et al. (2011) listed three strategies of adaptation to combat the health impact of air pollution. Ideally, the three strategies are used in a complementary fashion. First of all, reduce individual risk levels of citizens by interventions aimed at their exercise, nutrition and medication. Such interventions are most often incorporating different health issues at the same, hence not only aimed at the impact of air pollution. The second strategy involves the modification of citizen's activity time and location. For instance, an advice to run in the morning (cf. afternoon/evening) when ozone smog levels are lower could be given. This alters the activity time. Another example is an advice for cyclists to avoid routes with much traffic to minimize the inhalation or air pollutants. This alters the location. The third strategy to lower health impact is to separate sources from the public or the public from the sources. A good example that is currently employed in Amsterdam is the guideline on the zoning of housing for vulnerable citizens (*see section 5.2.3*). From the impact map follows that these strategies are mostly needed in district Noord, since this district houses the most vulnerable citizens.

The primary policy target - to reduce yearly averages of NO_2 concentration to its limit value of 40 $\mu g/m^3$ – is perhaps more difficult to tackle. The regression model developed in Chapter 2 indicates that the only significant predictor is a traffic variable, which implies that the only significant contributor of air pollution in the area examined is traffic. Consequently, policy measures must be aimed at reducing emissions from traffic. A study from the United Nations Environment Programme ordered numerous policy measures with respect to air pollution into four categories on cost: low cost, moderate cost, high cost and cost difficult to quantify (UNEP, 2011, p.14-15). This study found that policy measures related to traffic such as Euro 6 standards for heavy duty vehicles or light duty vehicles belong to the high cost category, whereas elimination of high-emitting vehicles is a member of the difficult to quantify category.

Another characteristic of ideal policy is that the different policy measures are well integrated and care has been taken to maximize synergies between them (Amann et al., 2011). Since national government has similar policy measures, for instance with regards to electric vehicles subsidies, integration between municipal and national policies is also a necessity for cost-efficiency. Consequently, environmental improvements are safeguarded, while the economic resources for their implementation are minimized.

Hence, the ideal evidence-based set of policy measures fits the following criteria. The set aims at reducing yearly average NO_2 concentration through reducing emissions from traffic. The set is exhaustive in nature, meaning that it incorporates policy measures with respect to all types of emitters in traffic. The set should focus on the heaviest polluters within the factor traffic. The limit value to be attained in 2015 is 40 $\mu g/m^3$. The ideal set also takes into account the health impact of air pollution by reducing individual risk levels, modification of citizen's behaviour and separating sources and public. Lastly, the set of policy measures needs to be well integrated horizontally, thus the municipal policy measures with each other, but also vertically, that is the municipal policy measures with the national policies.

5.4 Assessment of current policy and needed interventions over time

This section compares the *Current policy measures at work in Amsterdam* from section 5.2 with the *Ideal policy measures* from section 5.3. The first result of this comparison is an assessment of the current policy measures, which in its turn provides the basis for the needed interventions over time.

5.4.1 Assessment

From the ideal policy measures, it was derived that the policy measures should tackle the emissions from traffic. In fact, the city of Amsterdam focuses their entire set of air quality policy measures on traffic. As the 'low hanging fruits' have been harvested, further reduction of concentrations by addressing traffic calls for more expensive measures (Amann et al., 2011). Within the factor traffic, the heaviest polluters are those who drive daily (high total emissions) through Amsterdam or who have a highly polluting vehicle (high emissions/km). Frequent road users weigh in relatively heavily for they contribute to air pollution daily, and also often have diesel engines that pollute more than gasoline engines. This target group is effectively addressed by stimulating frequent road users to green their vehicle. However, policy to expel the second target group of highly polluting vehicles is currently lacking.

The different policy measures in Amsterdam are not at conflict with each other. The command and control measures, such as the Environmental Zone, provide the bare minimum standard that vehicles entering Amsterdam must meet. The market-based instruments, such as subsidies, stimulate renewal of the vehicle fleet beyond that bare minimum. In that sense, the two different types of policy instruments are complementary to each other. Given the doubling of some subsidies by the national government, vertical integration has also taken place.

In the ideal policy measures it was also pointed out that a public health component should be included. Advice on how the minimize the health impact of air pollution from the municipality or public health agencies such as the GGD could be improved. At the same time, as Giles et al. (2011) note, such advice most often incorporates different health issues at the same, hence it is not conveyed to the public as means of minimizing impact of air pollution specifically.

All in all, this assessment results in a mixed score for the set of policy measures with which Amsterdam fights air pollution. It succeeds in focusing on the emissions from traffic. The existing policy measures are well integrated on a horizontally and vertically. Helmink et al. (2013) report that for background measurement stations trends of decreasing NO_2 values can be observed. The decline per year amounts to approximately 0.5 $\mu g/m^3$. Measurement stations close to the street show both decreasing and increasing trends over time. On the other hand, the set of policy measures lacks a measure that targets the old and highly polluting vehicles. It is also not exhaustive in a sense that it covers all types of vehicles; buses, touring cars and mopeds seem to be excluded. Most importantly, the set currently fails at meeting the European Union standards for NO_2 concentration of 40 $\mu g/m^3$ by 2015, which makes intervention a necessity.

5.4.2 Interventions

Obviously, the interventions also need to satisfy the criteria mentioned at the end of section 5.3 *Ideal policy measures*. This section introduces the interventions that fill the gaps identified in section *5.4.1 Assessment*. In the first place, that implies making the set of policy measures exhaustive, hence also introducing policy measures for buses, touring cars and mopeds. Secondly, it means implementing a measure that targets the old and highly polluting vehicles.

The first intervention with respect to buses could be that the municipality promotes the transition to fuel cell buses used by the local public transport company (GVB), which are running on hydrogen gas. The transition provides ample room for emissions reduction, as hybrid electric buses have only one-half of the NO_x emissions of diesel buses (Shorter et al., 2005). From January 2012 until December 2014 two fuel cell buses are in service on route 22 (GVB, 2014). The knowledge and experience the GVB gains with this technology can be used in the future for expansion (A. Brakenhoff, personal communication, May 26, 2014)[2]. Currently, the GVB has capacity to produce hydrogen for six buses. The pilot project involves extra costs for the fuel cell buses in terms of maintenance, fuel and investment costs. The higher maintenance costs is related to failures of the system in the beginning of the pilot, but an extraordinary amount of failures does not occur at this point in time. The costs of fuel for driving 100 km with a fuel cell bus is approximately €150, using 10 kg of hydrogen gas. Yet, the total amounts to €75 for a diesel bus, combusting 1L per 2km. To contrast the investment costs: the fuel cell buses has been bought for €1.2m each, whereas a similar diesel bus can be acquired for €0.4m. All these prices are related to the start of the project in 2012, hence it is likely that by now the price difference has decreased due to a steeper learning curve for fuel cell buses (Schoots et al., 2010). A second policy measure - that is less costly - is to stimulate replacement of 23 busses that have a Euro 2 or 3 diesel engine by busses that comply to the Euro 6 standard for emissions.

[2] On May 26, 2014 I had an interview with A. Brakenhoff who is an employee of the GVB and in charge of the fuel cell bus project and procurement of buses in general.

As for touring cars, a policy plan called Touring car policy 2012-2020 has been written that limits the possibility for touring cars to take prolonged stops in Amsterdam (Amsterdam, 2012). Stewards arrange an effective flow of the touring cars at hotspots such as Damrak and also welcome the tourists. However, the implementation of the Touring car policy 2012-2020 seems to have stopped. Therefore, it is recommended that implementation and enforcement continues.

A policy plan aimed at moped is completely lacking. The municipality assumes that the number of mopeds is relatively small and that most polluting mopeds (2-stroke) will disappear from the streets automatically, as consumers switch to 4-stroke and electric mopeds (Gemeente Amsterdam, 2013). An organization that pursues a sustainable Amsterdam – De Gezonde Stad – has executed an extensive counting to get insight into the number of mopeds in Amsterdam. They arrived at 85,000 mopeds in total, out of which 44% were 2-stroke mopeds (De Gezonde Stad, 2013). In fact, mopeds with a blue sign (tampered mopeds) emit four times as much particulate matter as mopeds with a yellow sign (standard mopeds) due to the speed limiter (TNO, 2013). In their turn, standard mopeds emit more air pollutants than diesel cars (ibid.). Consequently, the municipality is recommended to shape policy with respect to mopeds. For instance, subsidizing electric mopeds, a scrappage scheme (sloopregeling) for 2-stroke mopeds, and/or exclusion of 2-stroke mopeds in the Environmental Zone.

To tackle the old and highly polluting vehicles, the recurrence of an old policy measure - the scrappage scheme – is proposed. This policy measure was enforced by the national government in 2009 and 2010. It was terminated once no money was available anymore. End of 2013, the city of Rotterdam decided to reintroduce the scrappage scheme for diesel vehicles manufactured before 2005 and gasoline vehicles produced before July 1992. A similar recurrence might take place in Amsterdam. The scrappage scheme should be complemented by additional conditions for parking permits. This policy measure has also been introduced in Rotterdam. It supplements the scrappage scheme, since the conditions prevent owners of diesel vehicles manufactured before 2005 and gasoline vehicles produced before July 1992 to obtain a new permit once the current permit has expired.

Chapter 6: Conclusion

The objective of this thesis was to research the air pollutant NO_2, build a land use regression model that maps NO_2 concentrations in Amsterdam, analyse the relation between the moderating variable socioeconomic status and health impact of air pollution, apply this relation in a spatial analysis to the Amsterdam area, and lastly, evaluate and propose policy measure that aim at reducing air pollution in Amsterdam. To reach this objective, the framework 'impact = exposure x vulnerability' was adopted.

Air pollutant NO_2: The air pollutant NO_2 was selected in this thesis as the unit of analysis for two reasons. From a theoretical perspective, nitrogen dioxide is a suitable proxy for a mixture of particles related to urban air pollution. The choice for NO_2 had also a practical reason: a decent amount of data from organizations such as Milieudefensie and GGD is available, most likely, because passive NO_2 monitors are relatively inexpensive to implement. The primary contributor to nitrogen oxide formation in urban environments is road traffic (Chapter 1).

Land use regression model (exposure): Only one traffic-related variable was found to be significant in the regression model: a variable that calculated the percentage of surface area in a 30m radius that is affected by a main road. The model predicts values ranging from 30.4 $\mu g/m^3$ (background concentration) to 45.3 $\mu g/m^3$, which was predicted for the midline of a main road (Chapter 2).

Socioeconomic status and health impact of air pollution (vulnerability): Air pollution contributes to both mortality and morbidity. As for morbidity, air pollution has been linked to respiratory illnesses such as asthma and cardiovascular illnesses. Income and age are the most important moderating socioeconomic variables on the health impact of air pollution. Income is taken as indicator for socioeconomic status and the lower income the higher vulnerability for air pollution. For age holds that from 65 years and older, vulnerability for high concentration levels rapidly increases (Chapter 3).

Health impact in Amsterdam (impact): Due to relatively high vulnerability of its citizens, citizens in district Noord are most likely to experience the fiercest impact of air pollution (Chapter 4).

Evaluation of Amsterdam's current set of policy measures: The evaluation resulted in a mixed score for the set of policy measures with which Amsterdam fights air pollution. The gaps involve the absence of policy measures against buses, touring cars and mopeds, but also against old and high polluting vehicles. The set currently fails at meeting the European Union standards for NO_2 concentration by 2015 (Chapter 5).

Proposed interventions: The first set of interventions aims at including buses, touring cars and mopeds in the set of current policy measures. The main point is that buses need to be renewed, touring cars should have a shorter turnaround time, and buying or having 2-stroke mopeds needs to be discouraged. The second set of interventions relates to old and high polluting vehicles. Notably, the recurrence of an old policy measure is recommended: a scrappage scheme (sloopregeling) supplemented by additional conditions for parking permits for diesel vehicles manufactured before 2005 and gasoline vehicles produced before July 1992 (Chapter 5).

Due to bureaucratic processes, these interventions will not ensure that Amsterdam complies with EU norms in 2015. Nevertheless, Amsterdam has an obligation to expand and/or deepen its current set of policy measures. In order to analyse evidence-based policy measures more in quantitative terms, it is recommended that future research calculates the effects in terms of reduced NO_2 concentration of certain policy measures, such as those proposed in this thesis. Research also needs to be conducted on the views and needs of citizens and firms located in Amsterdam. In particular, it is important to explore how they view their responsibility and their willingness to pay for cleaning the air of Amsterdam. Lastly, a multi criteria analysis on alternatives to combat air pollution will ease the decision-making process.

Chapter 7: Discussion

The results from this thesis clearly demonstrate the complex nature of spatial variation in air pollution, showing steep gradients of 60m horizontal length between a local maximum and absolute minimum (the background concentration). Nevertheless, this thesis shows that the variation in NO_2 concentration is to a certain extent predictable using information on emission sources.

7.1 Land use regression model

The implication of high spatial variation is that each measurement station provides a yearly average NO_2 value that represents a small surrounding area. Therefore, for useful monitoring of air pollution through air pollution exposure models a high density of measurement stations is needed. Given the R^2 of 0.54, land use regression models appear to offer an effective tool for mapping and predicting NO_2 concentration. Other authors showed slightly higher performance of land-use regression models for NO_2, as can be observed in Figure 12.

Reference	**Study area**	**Predictor variables**	$\mathbf{R^2}$
Briggs et al. (1997)	Amsterdam	Length major roads (50, 200, 350m), distance major road, built up land (100m)	0.62
Dijkema et al. (2011)	Amsterdam	Traffic volume at nearest road (50m), distance major road, green space (250m) water (100m)	0.72
Carr et al. (2002)	Munich	Traffic intensity (50m), traffic jam (50m)	0.77
Rosenlund et al. (2008)	Rome	Traffic zone, distance to busy road, inverse population density, altitude	0.69

Figure 12: Performance of land-use regression models for NO_2. In general, other studies used more predictors and obtained a higher R^2. The radius related to the predictor used in this thesis - % main road in buffer of ± 60m – is common in the literature.

Probably, the fit of the model in this thesis could be further improved by adding more predictors such as traffic intensity. However, data on traffic intensity was only available for the main roads. Remarkably, some predictors used by Dijkema et al. (2011) such as percentage green space or water were insignificant in my model. A reason could be different locations of the measurement stations.

In general, land use regression models have their limitations. Firstly, since the regression function is derived by a method of statistical optimization, the land use regression model may suffer from being area- or even city-specific (Briggs et al., 2010). Additionally, land use regression models merely take into account ambient (outside) air pollution, yet leave out factors related to infiltration in houses, for instance exchange rates (Hoek et al., 2008). Also time spent at home is not considered in land use regression models. It is assumed that citizens are continuously at their residence, which might be the case for the elderly in Noord, but not for all the citizens of Amsterdam.

7.2 Health-based policy measures

Although the European Union claims that its limit values for air pollutants are health-based standards referring to a WHO guideline, the WHO guideline originated from mostly indoor studies. A well established limit value still needs to be found. The limit value of 40 μg/m^3 is fairly arbitrary in that light and provides a fake sense of security. Given Figure 9 that was borrowed from Dijkema et al. (2011), the true health-based limit value is expected to be lower.

Obviously, more factors than individual risk play a role in the political arena. Public health, quality of life, environmental impact, societal impact and economic growth are all drivers that need to be considered. A present-day case involves the speed on the western part of the Amsterdam ring highway A10, which has been reduced from 100 km/h to 80 km/h in February, 2014. Milieudefensie (2013) stated that due to the increase from 80 km/h to 100 km/h citizens close to the A10 West lose 79 days of their life. However, the final decision of the minster of Infrastructure and Environment includes more considerations than only public health.

Regarding the spatial analysis on vulnerability, the scale of aggregation was minimized. The analysis served to highlight where the most vulnerable citizens live. Two remarks are in place here. Firstly, it is debatable whether the municipality desires to implement a differentiated policy across the city. Secondly, policymakers will mostly look at elderly homes to see where the most vulnerable citizens live. This is precisely what happens in the zoning of housing for vulnerable citizens. Interestingly, also small children are part of this zoning regulation, whereas the scientific literature concludes that small children are not at higher risk.

Additionally, data from different years were used: air pollution (2012), number of inhabitants (2008), mean income (2011) and % elderly (2011). It is assumed that especially the latter three are stable over time, in particular the relative difference across the city. Preferably, all data had come from the same year though.

7.3 Interventions proposed

In general, it should be noted that these interventions will not solve the non-compliance problem in time. Rather the interventions should be seen as recommendations on how the city of Amsterdam can show its good intentions when it fails to adhere to the European standards in 2015. A scenario that is discussed in the next section.

The extent to which the municipality of Amsterdam can influence the decision-making process within the GVB is questionable. The GVB is an independent corporation, but it is wholly owned by the city of Amsterdam, since its privatization in 2007. This involves an opportunity as well as a threat. The opportunity is that the city of Amsterdam as only shareholder has a say in how the business is run at the GVB. The threat is that if Amsterdam starts to financially promote this transition it could well be considered as state aid. However, the European Union provides exemptions to environmental state aid in their competition law regulatory framework, which means that state aid higher than

€7.5 million would be possible, if the municipality receives approval to use this exemption in Bruxelles (European Commission, 2008).

With respect to the interventions proposed on touring cars, mopeds and parking permits, it is important to keep in mind that the city of Amsterdam also needs to be livable for its citizens. The policymaker should balance the needs for regulation with the needs for freedom.

7.4 Scenario for non-compliance EU standard

If Amsterdam fails to comply with EU standards, Amsterdam would be represented by the Netherlands at state level, as only states are formally members of the EU. Only the formal member bear responsibility in legal and political terms. Thus, the states are responsible for actions, and in this case lack thereof, by all lower level government bodies.

In terms of enforcement, the European Commission would start an infringement procedure. This starts with a pre-litigation phase, involving investigations and formal notices. The aim of the European Commission here is to seek (quasi-)voluntary compliance by the Member State. Most likely, Amsterdam complies with EU standards by this time. This pre-litigation phase usually takes between four months to a year.

If all these attempts fail, which is highly unlikely, the European Commission can take the Member State to the Court of Justice of the European Union. This would be the start of a litigation procedure. The litigation procedure can last many years in total. The time is spent on going through several court cases. Ultimately, if a Member State were to continue to fail to comply with a Directive as well as the Court of Justice of the European Union's rulings, including payment of financial sanctions, in legal terms there is little that the European Commission can do to force the Member State to comply. However, politically the European Commission can pull many more strings. In fact, the European Commission has the authority to drop or not even start infringement proceedings against a Member State, if it feels it has a good reason to do so. [3]

Yet, as this thesis has shown, the city of Amsterdam has more than good reasons to comply with the EU standards.

[3] This section on infringement has been written based on correspondence with dr. Thijs Etty (VU) who is an expert in EU law.

Appendix I: Reclassification table

Old category	Old values	New category	New values
Infrastructure	1, 2, 3	**Other**	5
Residential area	4	**Residential**	1
Facilities	5	**Residential**	1
Industrial area	6	**Industrial area**	2
Other land use	7	**Other**	5
Other urban area	8	**Green/Park**	3
Building lots	9	**Residential**	1
Recreation	10	**Green/Park**	3
Greenhouses	11	**Industrial area**	2
Other agriculture	12	**Green/Park**	3
Forest	13	**Green/Park**	3
Dry natural area	14	**Green/Park**	3
Wet natural area	15	**Green/Park**	3
Fresh water bodies	16	**Water**	4
Salt water	17	**Water**	4
Exterior	18	**Other**	5

Appendix II: Output SPSS regression analysis

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	RoadBuf_30	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: NO2__ug_m3

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.733[a]	.538	.533	6.1761831

a. Predictors: (Constant), RoadBuf_30

Coefficients[a]

Model		Unstandardised Coefficients		Standardised Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	30.355	.921		32.958	.000
	RoadBuf_30	14.890	1.367	.733	10.895	.000

a. Dependent Variable: NO2__ug_m3

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	NEAR_DIST	.010[b]	.097	**.923**	.010	.451
	green_300m	.026[b]	.379	**.706**	.038	.999
	green_250m	.014[b]	.201	**.841**	.020	.997
	water_125m	.047[b]	.697	**.487**	.069	.994
	water_100m	.028[b]	.406	**.685**	.040	.993
	green_200m	-.014[b]	-.211	**.833**	-.021	.995
	water_75m	.037[b]	.544	**.587**	.054	.988
	INT_LV	.096[b]	1.427	**.157**	.141	.999
	INT_MV	.069[b]	1.020	**.310**	.101	1.000
	INT_ZV	.033[b]	.489	**.626**	.049	1.000
	green_500m	-.013[b]	-.186	**.853**	-.018	1.000

a. Dependent Variable: NO2__ug_m3

b. Predictors in the Model: (Constant), RoadBuf_30

Appendix III: Robustness of the model

FID	Observed	Predicted		SS about regression	Sum of squares due to regression
0	25.1	29.4		17.8	1.7
1	34.8	29.4		29.8	1.7
2	40.4	42.7		5.1	145.2
3	37.5	29.4		65.6	1.7
4	24.9	29.4		20.0	1.7
5	22.2	29.4		51.3	1.7
6	26.2	40.9		215.8	104.7
7	27.3	29.5		4.7	1.4
8	24.5	29.4		24.0	1.7
9	38.9	29.4		91.0	1.7
10	21.3	29.4		65.0	1.7
11	37.4	44.0		43.2	178.1
12	26.0	31.6		30.8	0.8
13	31.0	44.0		169.0	178.1
14	41.5	43.4		3.4	161.2
15	39.2	29.4		97.2	1.7
16	22.9	29.4		41.1	1.7
MEAN	30.7		SUM	974.8	786.6

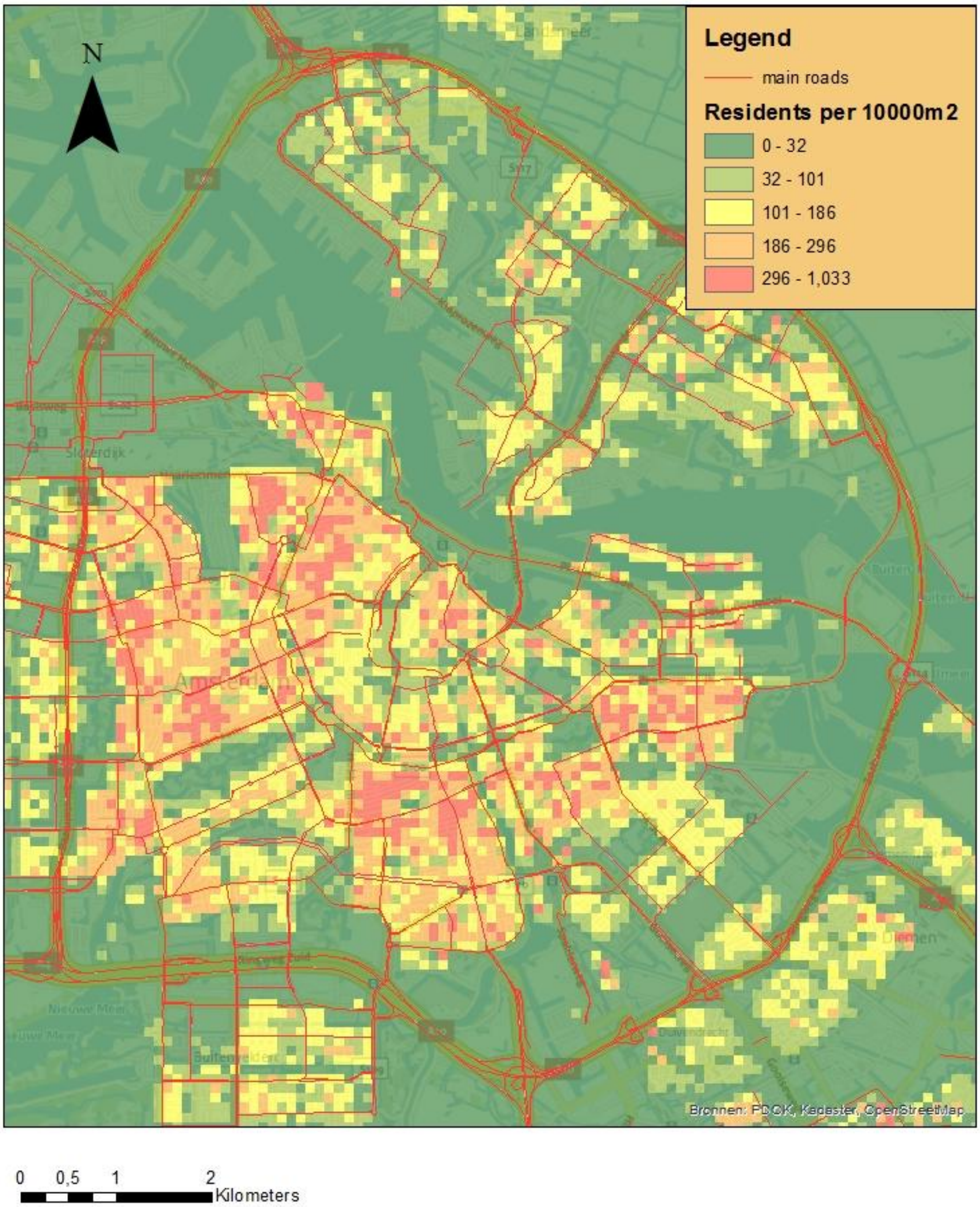
$$\sum_{i=1}^{n} (\mathrm{y_i} - \bar{\mathrm{y}})^2 = \sum_{i=1}^{n} (\mathrm{y_i} - \hat{\mathrm{y}}_\mathrm{i})^2 + \sum_{i=1}^{n} (\hat{\mathrm{y}}_\mathrm{i} - \bar{\mathrm{y}})^2$$

And

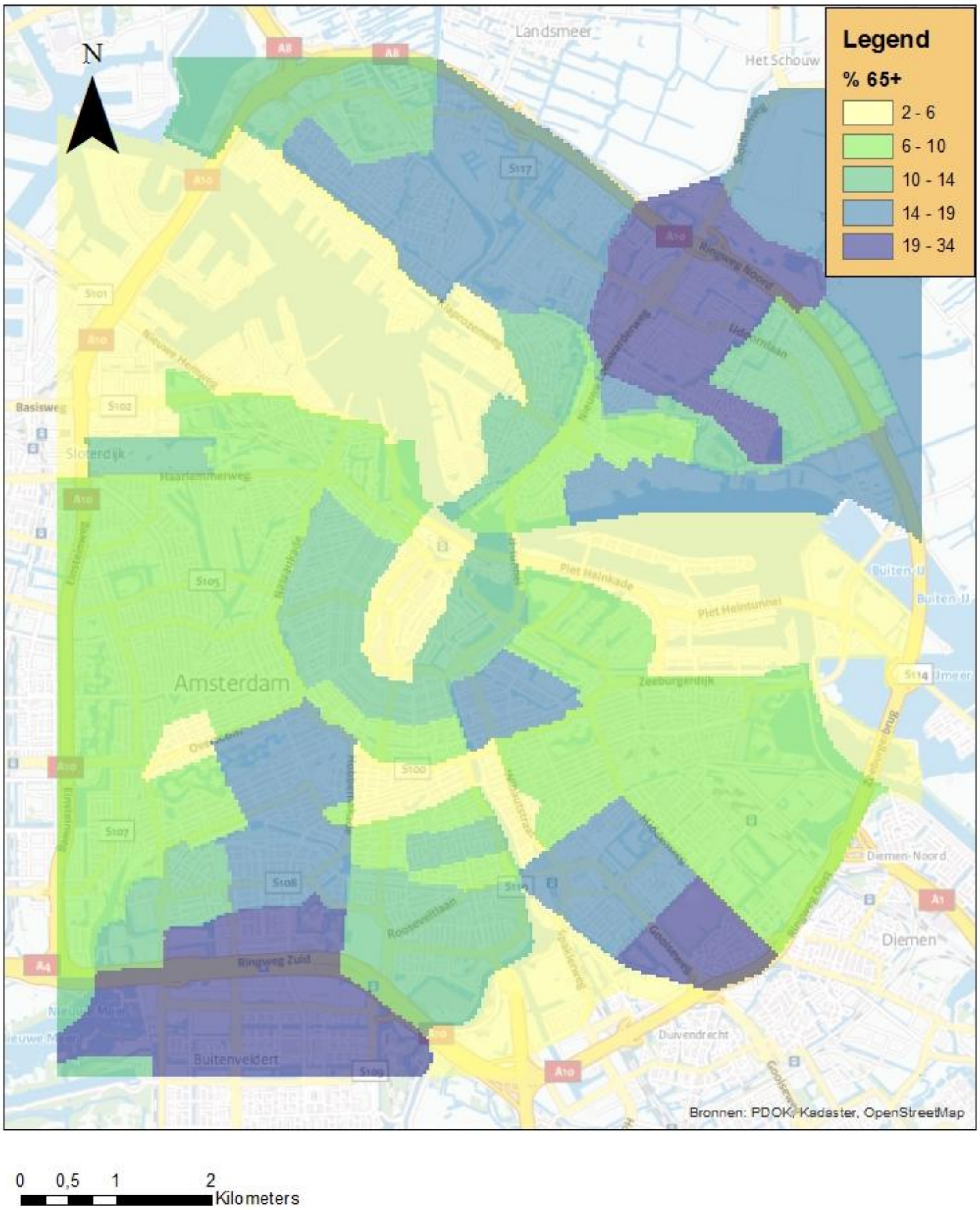
$$R^2 = \frac{sum\ of\ squares\ due\ to\ regression}{sum\ of\ squares\ about\ the\ mean} = \frac{\sum_{i=1}^{n} (\hat{\mathrm{y}}_\mathrm{i} - \bar{\mathrm{y}})^2}{\sum_{i=1}^{n} (\mathrm{y_i} - \bar{\mathrm{y}})^2} = \frac{787}{975 + 787} = 0.45$$

Where $\bar{y}$ = 30.7, $\hat{y}$ = predicted value, and y = observed value.

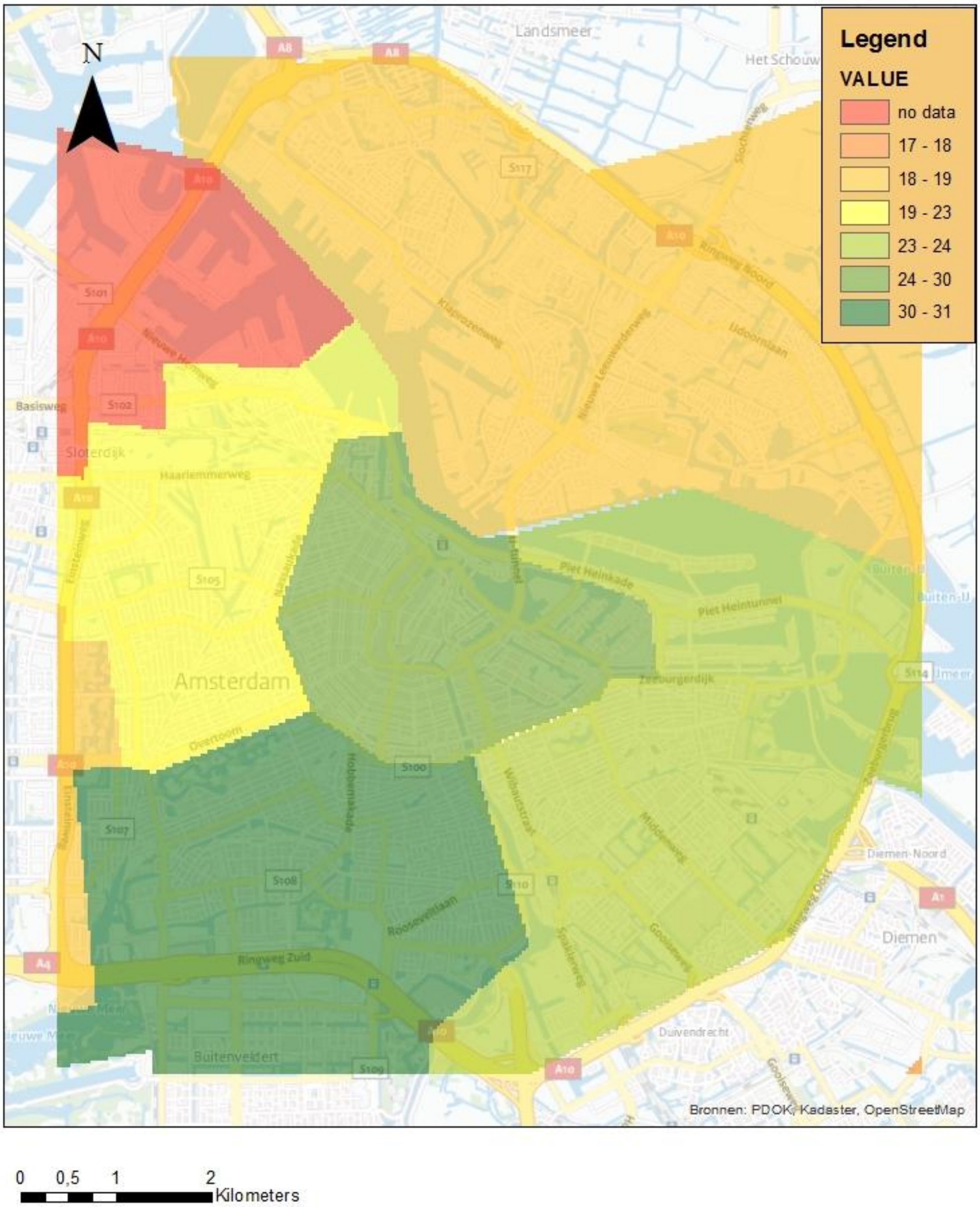
Appendix IV: Variable ‘number of inhabitants per 10000 m^2’



Appendix V: Variable 'percentage elderly of total population'



Appendix VI: Variable ‘mean income x€1000 per district’



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