UNIVERSIDADE DE LISBOA

INSTITUTO DE GEOGRAFIA E ORDENAMENTO DO TERRITÓRIO

THE USE OF GIS TO ANALYZE THE ENVIRONMENTAL AND SOCIAL INFLUENCE TO MEDICATED ASTHMA IN NEW ZEALAND

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MESTRADO EM SISTEMAS DE INFORMAÇÃO GEOGRÁFICA E MODELAÇÃO TERRITORIAL APLICADOS AO ORDENAMENTO

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Dissertação orientada pelo Prof. Doutor Eusébio Joaquim Marques dos Reis
Co-orientação: Prof. Doutor Nuno Manuel Sessarego Marques da Costa

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O uso de SIG para a análise da influência ambiental e social asma medicada na Nova Zelândia

Janina Saskia Katharina Bäumler

Resumo

Esta dissertação incide na análise da relação entre a asma e as diversas variáveis espaciais independentes, ambientais e sociais, que se suspeita terem alguma influência na ocorrência desta doença, tendo como referência o território da Nova Zelândia. Os dados baseiam-se na utilização da “asma medicada”, ou seja, que inclui não apenas as consultas em hospitais e centros de saúde, mas também os casos em que ocorreu tratamento preventivo e medicação da asma. Para este efeito, o trabalho assenta na utilização de Sistemas de Informação Geográfica (SIG) e utiliza os algoritmos de Análise de Correlação Multivariada (Multivariate LISA), presentes no programa “Open GeoDa“ e a Análise de Regressão (*Ordinary Least Squares* e *Geographically Weighted Regression*) presente no *software* ArcGIS (versão 10), com base na ferramenta “Exploratory Regression”. A variável “asma medicada” é representada por *Census Area Unit* (CAU). O objectivo principal é descobrir quais variáveis que determinam a distribuição espacial da “asma medicada” na Nova Zelândia, e, através da sua combinação, construir um modelo adequado. A Nova Zelândia é um dos países do Mundo com a maior preponderância de asma; a análise é feita para todo o país, mas também para a região de Auckland. A razão pela qual a região de Auckland é seleccionada para a análise é porque é mais influenciada pela poluição do ar que o resto de Nova Zelândia. Além disso a cidade de Auckland é a cidade mais povoada da Nova Zelândia. Para a análise regional foram utilizadas somente as variáveis sociais; para a análise nacional as variáveis ambientais e sociais foram consideradas. As variáveis ambientais utilizadas para a análise nacional foram: temperatura (média e mínima), balanço hidrológico, humidade, precipitação, velocidade do vento, altitude, grau de urbanização, ocupação do solo, poluição do ar (PM_{10}, $PM_{2,5}$) e densidade de estradas. No caso da região de Auckland, as variáveis ambientais não foram analisadas através da Análise de Correlação/ Análise de Regressão. Contudo, a localização de autoestradas e dos aterros sanitários foram tidas em conta. As variáveis sociais utilizadas foram: idade, etnia, número de crianças, número de quartos, educação, renda pessoal, renda familiar, situação de emprego, *New Zealand Deprivation Index*, meios de deslocação para o trabalho, tipo de aquecimento, emissões domésticas de aquecimento (PM_{10}) e densidade populacional (esta só para a análise nacional).

Após o mapeamento da distribuição da “asma medicada” para a Nova Zelândia e para a região de Auckland, foi aplicada a análise de *cluster,* a qual mostra que existe um *clustering* das *Census Area Units* com alta / baixa prevalência de asma. De seguida, aplicou-se a Análise de Regressão e a Análise de Correlação, para examinar a relação de cada variável dependente com a variável independente (“asma medicada”).

Os resultados mostram que a análise é mais precisa para o âmbito regional, pois apresenta um “R^2 ajustado” (Análise de Regressão) e um Moran´s I (Análise de Correlação) mais altos para a maioria das variáveis individuais e tem também um R^2 ajustado mais alto para o modelo. Na análise regional, diversas variáveis mostram uma relação forte. A percentagem da população da etnia ”Pacific Islanders“ (R^2 ajustado: 0,41; relação negativa) e a percentagem das famílias com 2 crianças (R^2 ajustado: 0,50; relação positiva) têm um R^2 ajustado e Moran´s I alto. No caso da situação económica, verifica-se que as CAU com uma elevada proporção de classe social mais elevada têm também uma taxa aumentada de “asma medicada”. As variáveis renda pessoal (R^2 ajustada: 0,43) e renda familiar (0,46), a percentagem da população desempregada (R^2 ajustada: 0,29) ou empregada a tempo parcial (R^2 ajustada: 0,28) têm, todas, uma relação positiva com a prevalência de “asma medicada”. Em contrapartida, a proporção de pessoas sem educação escolar (R^2 ajustada: 0,22) tem uma relação negativa. À primeira vista é um resultado inesperado; no entanto, esta situação pode ser explicada pelo facto do indicador usado para representar a prevalência da asma ser a "asma medicada". Isto pode significar que pessoas com melhor situação financeira disponham com maior facilidade de medicação preventiva ou visitas ao médico de família do que as pessoas com baixa renda.

Para a análise nacional o tipo de relação foi a mesma que para as variáveis sociais; no entanto, o grau de relação foi muito mais baixa do que para a análise regional. A observação de que as classes sociais mais elevadas parecem ter uma maior prevalência de asma é confirmado na análise nacional.

A Análise de Regressão e de Correlação para as variáveis ambientais (executado à escala nacional) mostram que o “R^2 ajustado” e o “Morans´I” são, em geral, pequenos. A variável que melhor descreve a distribuição da prevalência de “asma medicada” é o grau de urbanização (R^2 ajustado: 0,21; Moran´s I -0,4204). A relação negativa significa, neste caso, que a população em áreas urbanas é mais afetada do que a população em áreas rurais. Além da variável grau de urbanização, o " R^2 ajustado" para as outras variáveis é apenas 0,10 no máximo (poluição do ar $PM_{2,5}$). 9% do padrão da “asma medicada” pode ser explicado usando o balanço hidrológico (relação negativa) ou precipitação (relação positiva).

As variáveis “superfícies artificiais” (relação positiva), a “área da floresta” (relação negativa), a “poluição do ar a partir de fontes naturais” (relação negativa), a “densidade de todas as estradas” (relação positiva) têm, todas, um R^2 ajustado de 0,08, o que significa que podem explicar 8% da distribuição da prevalência de “asma medicada”.

Para o modelo, as 5 variáveis mais adequadas podem explicar 73% do padrão de asma tratado para a região de Auckland (utilizando Geographically Weighted Regression). Este valor é bom, no entanto o modelo não passa o teste de "Moran´s I p-value", que verifica a autocorrelação espacial. Para a análise nacional obtém-se apenas 26% (OLS)/ 33% (GWR), quando se utilizam 5 variáveis ambientais e 33% (OLS) / 48% (GWR) quando se utilizam 5 variáveis sociais. Adicionalmente, construi-se um modelo através d combinação de variáveis sociais e de variáveis ambientais. A ferramenta “Exploratory Regression” do ArcGIS selecciona as variáveis com essa finalidade: percentagem da famílias com 6 e mais crianças, percentagem de população com renda pessoal acima de 50.000 NZD, percentagem que viaja para o trabalho de carro, grau de urbanização e precipitação; o R^2 ajustado utilizando OLS é 0,36 e com GWR é 0,45.

Os resultados da Análise de Regressão mostram que, mesmo com uma grande variedade de variáveis, pode-se considerar que ainda faltam variáveis principais para que seja possível formar um modelo que possa satisfazer as exigências de forma satisfatória. A cartografia da doença mostra que existe uma relação forte entre poluentes como H_2S e SO_2 e as áreas com asma. No entanto, não foi possível incluir estas variáveis na Análise de Regressão e Correlação porque não há dados nacionais.

Limitações da análise e dos resultados resultam dos dados individuais não estarem acessíveis, mas apenas a taxa por CAU. Isso significa que, especialmente para as variáveis sociais, há uma maior incerteza. Além disso, a residência da população foi considerada, mas pode ser que uma pessoa trabalhe ou vá à escola em outro CAU e esteja exposta também, e de forma regular, às variáveis ambientais deste CAU.

Palavras-chave: SIG, asma medicada, método dos Mínimos Quadrados, Regressão Ponderada Geograficamente, Nova Zelândia

The use of GIS to analyze the environmental and social influence to medicated asthma in New Zealand

Janina Saskia Katharina Bäumler

Abstract

This GIS study uses correlation analysis (Multivariate LISA) through Open GeoDa and regression analysis (Ordinary Least Squares and Geographically Weighted Regression) through ArcGIS 10 to analyze and examine the relation of medicated asthma and independent environmental and social variables that are suspected to influence the disease of asthma. The main target was to find out which variables determine the spatial distribution of medicated asthma throughout New Zealand to later combine these variables to build a suitable model. A regional scale analysis is carried out for the Auckland region, combined with a national scale analysis for New Zealand (main islands). For the Auckland regional only social variables are tested, while the nationwide analysis included environmental and social variables.

The findings show that the analysis is more accurate for the regional scale, which reaches a much higher adjusted R² (regression analysis) and Moran´s I (correlation analysis) for the majority of the individual variables, but also for the entire model. The social variables all in all were more suitable to explain the pattern. 73% of the spatial distribution of medicated asthma of Auckland could be explained through a selection of the 5 most appropriate variables (using Geographically Weighted Regression). For the national model only 26% (OLS) / 33% (GWR) using 5 environmental variables and 33% (OLS) / 48% (GWR) using 5 social variables could be explained. Selecting 5 variables of either social or environmental characteristics explains 36% (OLS) / 45% (GWR) of the medicated asthma prevalence. The output results of the regression analysis made it clear that despite the variety of variables tested, key explanatory variables are still missing. The disease mapping part leads to the assumption that air pollutants for which no national wide measurements exist (H_2S, SO_2) play an important role with the distribution of asthma.

Keywords: GIS, medicated asthma, Ordinary Least Squares, Geographically Weighted Regression, New Zealand

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As a final remark I would like to note, that even though, going through highs and lows while analyzing and writing the thesis – it was a great and valuable experience which I am grateful to have had and would like to thank everyone who has made this possible.

Muito Obrigada!

1.Introduction

When the English Doctor John Snow discovered the connection of drinking water pumps and cholera cases in the 19th century, he basically set the roots for medical geography and realized that there is a link between health or disease and with geography/space. By plotting cholera deaths in London, he was able to locate clusters around water pumps which were infected and as a result concluded that cholera is water-borne (Brody *et al.,* 2000). His discovery was a profound and fundamental step for disease mapping. Many illnesses are influenced or even based on geographical factors, such as climate, the availability and quality of water, altitude and more. Apart from that, human living conditions and style such as nutrition, hygiene, type of dwelling, economy or income also vary highly throughout the planet and have an impact on health and disease (Meade & Emch, 2010). Medical Geography tries to understand the health conditions and problems that are influenced and caused by geographical variables (Meade & Emch, 2010). Nowadays many researchers and institutions, like for example the World Health Organization or Centers of Disease Control and Prevention, use geographical methods to enlarge the understanding of diseases and thus being able to take precautions and effectively intervene (Meade & Emch, 2010).

Widely used in Medical Geography are Geographical Information Systems (GIS). Especially since the 1980s GIS has evolved as essential technology for optimal use and benefit of spatial data (Taylor & Jankowski, 2007). A Geographical Information System, commonly referred to as an information system, of which the database consists of observation of spatial objects, activities or events, which are defined through points, lines or polygons (Bartelme, 2005) enables the user to collect, store, implement and distribute a huge amount of data that can be used to analyze and model spatial relationships. GIS allows the linkage between geometric, graphical and attribute data (Bartelme, 2005). Therefore it enriches all subfields of geography, where spatial data is relevant. As a consequence also Medical Geography highly profits of GIS since relevant data can be assessed and by using spatial analysis methods, the correlation between health problems and spatial factors can be observed. Furthermore GIS can be used for planning, so that access to health care is optimized. The use of GIS in Public Health is a method, which can help in maintaining and improving peoples´ highest good – their health.

With asthma being a widely spread disease in both developed and underdeveloped countries, it has become a common illness all around the World. The reasons for the development and severity of the disease asthma are not fully understood yet and are considered to be very complex. Using GIS to approach the variables that can provoke asthma is a suitable method to benefit of obtainable data and investigate the influence of the factors by using spatial analysis methods. Since it would be quite time-consuming or superficial to do an analysis for the entire world population, it is helpful to narrow down the area and its habitants. To restrict the area under investigation for this work the country New Zealand was chosen, where asthma is one of the most common chronic diseases (Holt & Beasley, 2001). Depending on the variable and data, different scales are used on both regional and national scale.

This dissertation is based on an internship at the Ministry of Health of New Zealand located in Wellington. The Department of Health and Disability Intelligence, which is responsible for Statistics and Health Survey within the Ministry, includes asthma in their research and also makes use of GIS to plan health care provision and grasp the health situation of New Zealanders. The internship placement of the Ministry of Health made it possible to access reliable data and was also a great opportunity to gain experience in the working environment where Health GIS is applied. The internship took place from October to December in 2011.

To understand the principles of the disease asthma and in particular in New Zealand this paper introduces the components – the disease asthma and the study area - of the topic under the chapter “Background” (chapter 2) which covers general information about asthma (chapter 2.1), followed by general characteristics of the country New Zealand (2.2). Subsequently the chapter about Background information finishes of with more detailed information about the situation of asthma in New Zealand based on literature review (2.3). In the subsequent chapter 3, the data (3.1) and methods (3.2) are described. The data is built up from spatial and administrative data of New Zealand, the dependent variable prevalence of “medicated asthma” as well as explanatory variables used to approach the justification of spatial distribution of asthma. Medicated asthma (used for the years 2009/10) is an indicator, established by Craig Wright from the Ministry of Health (HDI Department) that includes ICD codes for both J45 and J46 in any national health collection (NMDS, MHNC, PMHD, Pharmbase, Socrates) and/or 3 or more dispensing for specific anti-asthmatic drugs (inhalers) per year in Pharmbase, over a 10 year look back period, who are still alive in 2009/10. Methods include the literature review and necessary data collection/preparation, simple disease mapping and finally the actual spatial analysis approach through Regression and correlation analysis. The results are presented under chapter 4, followed by the conclusion and discussion (chapter 5) about the outputs and findings as well as profits and limitation of this analysis.

1.1 Motivation for this study

The motivation for choosing this topic for the Master Thesis comes from a personal interest in health topics. Asthma in particular seems to be a disease that has multiple possible influencing factors of both physical and human geography alike. Even though many researchers and institutions are trying to fully understand the reasons for asthma distribution, there are still gaps, which might be revealed with the use of GIS. With the use of spatial analysis methods, it is possible to combine the spatial data and variables with asthma rates per area in order to make conclusions on which factors actually are responsible for the high asthma rate in New Zealand. Furthermore the mapping of asthma rates and possible risk factors as location of highways for example allows conclusions. The high prevalence of asthma is not only a burden for individuals that are affected by asthma, but also for the health care system, since the economic costs of asthma add up to more than 800 million New Zealand Dollar per year (Holt & Beasley, 2001). Considering the burden for asthmatics and the economy of New Zealand there is a high need in finding solutions to lower the rate of asthma, which primarily can be done by identifying specific causes for asthma in New Zealand. Using GIS to examine the distribution of asthma within New Zealand and linking the rate with factors that can provoke asthma is a potential method to bring the prime reasons of increased asthma prevalence to light. This work aims to find significant correlation of selected variables with high or low asthma appearance.

2.Background

2.1 Asthma

2.1.1 Principles of asthma

The term asthma stands for an inflammation which occurs in the respiratory tract. This inflammation leads to a swelling and causes the mucous membrane to secrete phlegm. Meanwhile the muscles are contracted which is accompanied by a narrowing of the respiratory system. As a consequence the affected person will have difficulties breathing. As the inflammation, and not the narrowing of the bronchus, is the primary problem, anti-inflammatory medicine is given to asthmatics, when suffering an attack (Simon, 1998). There are two main forms of asthma: the allergic and non-allergic asthma. Allergic asthma, which is also known as atopic or extrinsic asthma, is caused by the exposure to allergens. The sensitization to atopic asthma often takes place during childhood and early adolescence. Meanwhile non-allergic (non-atopic or intrinsic) asthma is more common within patients older than 40 years. Intrinsic asthma is often provoked after a respiratory infection (Kroegel, 2002).

2.1.2 Global burden of asthma

Asthma is a very common chronic disease in both western industrialized countries and underdeveloped countries. The prevalence has increased all over the world during the last 40 years with an increase of about 50% per decade (Braman, 2006). Hospital admissions and the rate of severe asthma are especially high in young children. It is estimated that approximately 300 million people currently have asthma. About 180,000 persons die each year as a consequence of asthma. While asthma used to be a disease that was mostly common in developed countries only, there has been a sharp increase in underdeveloped countries as well, supposedly due to their increasing industrialization.

The high prevalence of asthma results in major financial costs for the health-care systems. In Europe alone, the economic burden of asthma is approximately 17,7 billion Euros per annum. Figure 1 illustrates the global distribution of asthma by showing the proportion of the population suffering from clinical asthma (Masoli *et al.*, 2004). As Asthma is difficult to determine, as there is no standard test, Masoli explains that in this report he uses “an arbitrary figure of 50% of the prevalence of "current wheezing" in children (self- reported wheezing in the previous 12-month period in 13- to 14-year- old children)” to determine the “prevalence of clinical asthma” (Masoli *et al.*, 2004). The map shows that the highest percentage (over 10%) is in Canada and the U.S. (North America), Brazil, Peru and Costa Rica (Latin America), in the U.K. (Europe) and both Australia and New Zealand. It has to be noted that no standardized data is available for most countries of Africa. Some gaps also appear in Latin America and Asia.

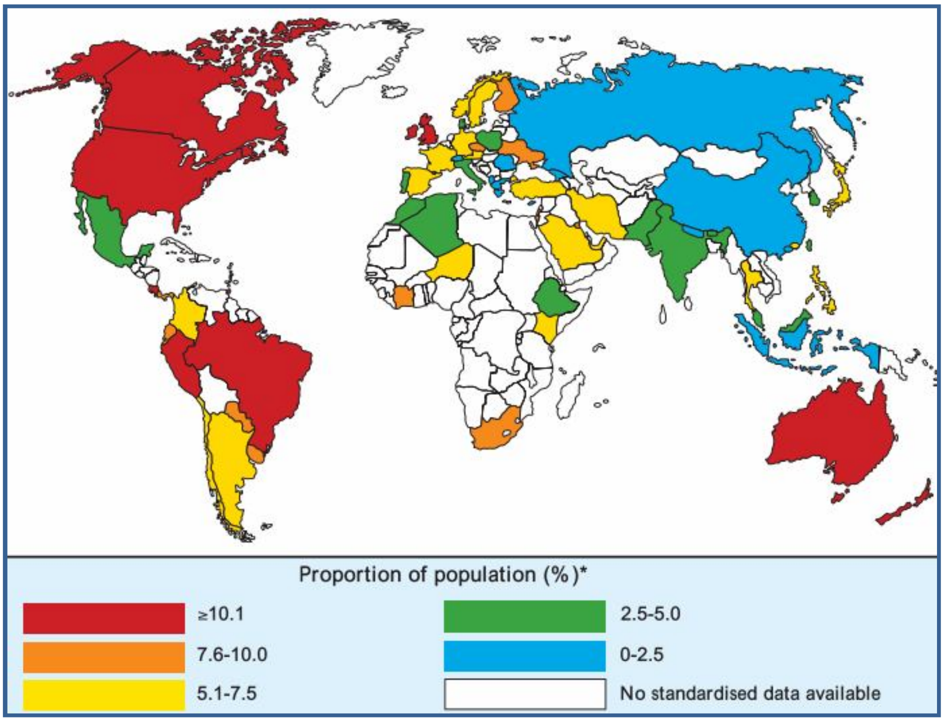


Figure 1 - World map of prevalence of clinical asthma

Source: Global Burden Report of Asthma, Masoli, *et al.* (2004).

2.1.3 Common causes for asthma

Asthma affects people throughout the world of industrialized as well as non-industrialized countries, upper and lower classes and both population living in cities and on the countryside. Nevertheless there still is some geographical variation (see chapter 2.1.2) as well as temporal differences which give indication of possible causes for asthma. According to Magzamen (2007) physical space is a main factor that influences the disease of asthma. Past studies have shown that there is a diverse range of triggers, whereas a lot of them are only assumptions at this point since it is difficult to give full evidence. The environment, where the individuals spend much time especially in the early years of their life is of high influence for atopic asthma (Epton, 2007). The most acknowledged causes are presented on the following pages in more detail.

Air pollution

Air pollution is well known to affect the respiratory tract and thus it is also one of the main suspects to provoke asthma. There are several different air pollutants that may play a role. Nitrogen Dioxide (NO_2) is a problem in terms of asthma and respiratory diseases because it "increases the cell membrane permeability, decreases ciliary beat frequency and increases the response of asthmatics to inhaled allergens" (Ferguson, 2004). In the outdoor environment a high NO_2 concentration is often caused by traffic. Ferguson (2004) states that almost 50% of NO_2 come from car and diesel exhaust fumes. Other sources of NO_2 are power stations and industries (Burr, 1995). Indoors NO_2 is emitted from unflued gas heaters and cookers. Therefore, households that use gas stoves and heaters have usually higher NO_2 indoor levels than homes using electric sources (Gillespie-Bennett *et al.*, 2011). According to the Ministry of Health Report (New Zealand) on asthma, from 1996, NO_2 is a pollutant that irritates the respiratory system in general but effects asthmatics and non-asthmatics equally. Several studies could however relate high NO_2 concentration with asthma (Ferguson, 2004; Shima & Adachi, 2000).

Furthermore Sulphur Dioxide (SO_2) is another air pollutant that has been brought into relation with a high asthma rate. SO_2 arises when fossils like coal and oil are burned, but for example also from power stations (Burr, 1995). SO_2 levels are also increased at areas with geothermal activities (Ministry of Health, 1996). Besides at geothermal bores also the gas Hydrogen Sulfide (H_2S) is emitted. Especially during foggy days, H_2S remains in the area and within a lower altitude where it can harm the human health, among others the respiratory tract (http://www.osh.dol.govt.nz/order/catalogue/hydrogensulphide.shtml). Durand & Wilson (2006) examine the effects of geothermal energy to respiratory health in New Zealand (in the Rotorua and Taupo area) and find a higher risk for noninfectious respiratory disease within humans living within the geothermal area. In general H_2S is considered as acutely toxic and may even be fatal when the concentration is over 200 parts per million (Durand & Wilson, 2006). The Agency for Toxic Substances and Disease Registry also counts landfills to the sources of Hydrogen Sulfide (www.atsdr.cdc.gov). Other pollutants that have an impact on asthma are O_3 (Ho, 2007), NO_x (Ferguson, 2004), CO and CO_2, which are highly produced by traffic (Ho, 2007) and NO arising from gas heaters and cookers (Ministry of Health, 1996).

Allergens

Dust mites are a prime allergen for asthmatics. Their survival requires a humid (over 50%) and cool environment. As a consequence house dust mites are more likely to be present in humid and coastal areas but at the same time there is an increase of house dust mites during the winter as well. Since higher air temperatures are dehydrating, mites favour a temperature of around 25 ºC as an optimum (lifecycle requires one month). If the temperature is 15 ºC, the lifecycle will take much longer than at 25 ºC, but more mites will be able to complete their lifecycle and survive compared to when the temperatures are at 25 ºC. For the indoor environment, home heating is not only of importance regarding the emissions as mentioned previously, but also a determinant due to its effect on the survival of house dust mites. Poor heating and bad ventilation are in favour of house dust mites and enable them to reproduce and survive (Ministry of Health, 1996). The type and quality of home heating also determines mould growth which is another major allergen for asthma (Webb, 2010). Multiple studies have been able to prove the association of both sensitisation and severity of asthma (Wilson, 2007) through mould. Wickens *et al.* (1997) observed, in a study about dust mites in Wellington (New Zealand), that the number of children per household and the number of persons sharing a bedroom significantly influenced the presence of dust mites levels. Apart from dust mites also grass pollen are an important suspect when it comes to sensitization of asthma and provoking an actual attack (Sears *et al.*, 1989). On the other hand, Mutius *et al.* (1994), according to of Ministry of Health (1996), found a negative relationship between higher prevalence of asthma and number of children. It is speculated that this may be due to the more frequent viral exposure during early childhood with more siblings which lowers the Immunoglobulin E production. As the Asthma and Allergy Foundation of America informs IgE plays an important role with allergic diseases, as the antibody connects with the allergen and causes a release of substances from the mast cells. As a result the inflammation and allergic reaction can be triggered (http://www.aafa.org/display.cfm?id=8&sub=16&cont=54). A reduced IgE production (in this case as a result of increased viral exposure during early childhood) therefore can affect the prevalence of asthma for people that grew up with more siblings compared to an only child.

Climate

Climatic factors can affect asthma symptoms not only directly but also indirectly; Hales & Lewis *et al.* (1998) studied the correlation of climate with prevalence of asthma for 1993 and found that warmer average temperatures were linked with higher prevalence of asthma, possibly due to higher level of allergen exposure. They also found that higher variability of relative humidity goes along with lower asthma prevalence (linear trend). At the same time a relationship between low asthma rates in areas with low mean temperature, high rainfall and a high variability of these factors was observed (Hales & Lewis *et al.*, 1998). Rainfall on the other hand may also increase probability of asthma due to higher occurrence of mould (http://www.idph.state.il.us/public/hb/hbasthma.htm), and must be seen critical when trivialized. Considering elevation, Hales & Lewis *et al.* (1998) observed lower asthma rates in higher altitudes. Furthermore, according to the Illinois Department of Health, wind can aggravate asthma as well, since it increases the distribution of pollen and other allergens (http://www.idph.state.il.us/public/hb/hbasthma.htm).

Housing

Next to type of heating/cooking, which is mentioned under the point “Air pollution” and “Allergens”, the number of bedrooms has also been observed as having an impact on asthma (as already noted under the point “Allergens”). A national telephone survey for New Zealand, carried out through Howden-Chapman *et al.* (2005) (according to Wilson *et al.*, 2007) found out that a higher number of bedrooms (more than 3) is accompanied by an increased risk of asthma. This observation is justified by an increased probability for mould - one of the major allergens for asthmatics. Also Wickens *et al.* (1997) found that having 3 or more children per household is associated with higher dust mite level (in this case tested for D. pteronyssinus – the most common mite in Wellington, New Zealand). The same appears for households with 5 or more people and with 1 or more people sharing a bedroom (Wickes *et al.*, 1997). In this study Wickens *et al.* (1997) also found, that the type of mattress had a major influence on the concentration of D. pteronyssinus.

Lifestyle

Last but not least lifestyle has an impact on asthma as well. Often discussed is the use of tobacco, which contains Formaldehyde. It is proven that tobacco irritates the airway systems, but it is not clear yet, whether the use of tobacco actually sensitizes persons for being asthmatic (Ministry of Health, 1996). However it is a fact, that tobacco increases the IgE serum concentration, so it can lead to a higher sensibility to allergens in general and thus also for allergens that provoke asthma (Shaw *et al.*, 1990).

Additionally the diet plays a role. The consumption of unpasteurized milk during childhood increases the overall sensibility to allergens (Wickens, 2002). When trying to explain the rise of asthma during the last decades an assumption is that the reduced intake of fruit and vegetables causes a lack of Vitamin C, beta-carotene and other antioxidants which leads to an “oxygen radical airway inflammation” (Ministry of Health, 1996). Simultaneously there is an increased exposure to radicals (like tobacco or air pollution) nowadays.

The wide range of possible trigger for asthma, and yet a partially unresolved scientific prove for some of them make it difficult to fully understand the causes for geographical variation of asthma throughout the planet. Certainly it is a complex combination of circumstances, of which some are difficult to measure and grasp.

Masoli (2004) points out that the currently known causes for asthma do not fully explain the international spatial distribution of asthma. The Global Initiative for Asthma therefore counts research into causation of asthma as one of the prime research priorities in asthma research.

2.2 The area under investigation: New Zealand

This chapter introduces the study area New Zealand as a whole with a focus on the Auckland region in particular as well.

2.2.1 Study Area

The purpose of this study is to identify risk factors for asthma in New Zealand. However a more detailed scale analysis is applied as well to be able to grasp triggers more easily (Figure 2). This allows taking a closer look on observations and characteristics of the area. The urban area of Auckland was chosen for the regional analysis, since it is the most populated city and region of New Zealand. Also Auckland is known for higher pollution than other parts of New Zealand. Only for the mapping of geothermal bores the area of the Taupo Volcanic Zone is subject of detailed investigations as well.

As a suitable unit for the analysis Census Area Units are selected. This is because even on a higher scale analysis Meshblocks tend to be too small (due to their irregular population size). The varying number of people per Meshblock can cause bias, for example when a Meshblock has only two inhabitants and, possible by coincidence, both persons of them are asthmatics, a rate of 100% occurs. However this rate may not be representative and appropriate. Apart from that, even on the scale of a city, the maps lose their overview and some unit cannot be seen clearly.

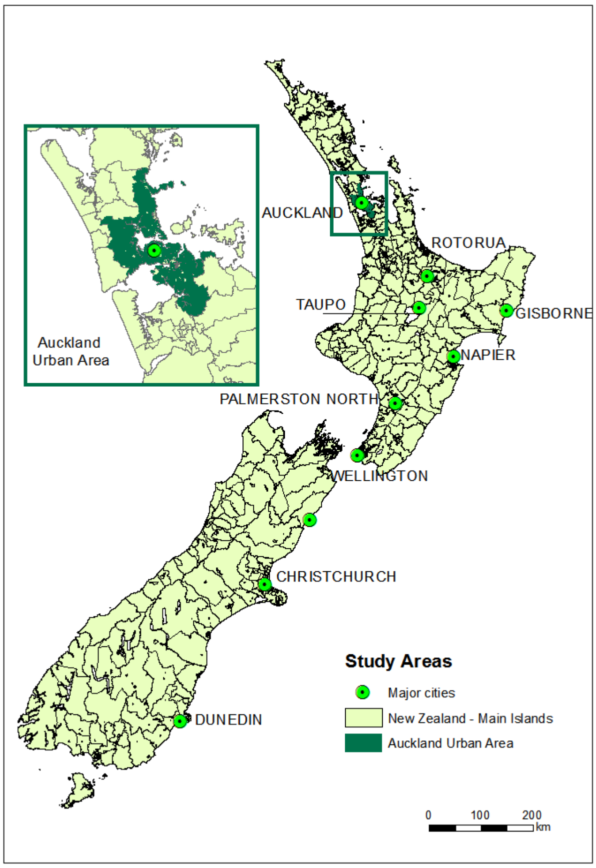


Figure 2 - The Study Area: location of Auckland sub region in New Zealand

2.2.2 Location and administrative divisions

New Zealand covers an area of 263,830 km² with a total extension of 1500 km from North to South. The latitudinal range goes from 34°09´to 47°17´ (Wardle 1991). The country is divided into 14 regional councils. However, in terms of Health Care, the Ministry of Health also distinguishes amongst 20 District Health Boards (DHB) as major administrative boundaries. All the funding and providing of health services is done and organized by the DHBs for their district. Only a few disability support and health services are administrated nationally (by the Ministry of Health) (http://www.health.govt.nz/new-zealand-health-system/key-health-sector-organisations-and-people/district-health-boards). For the main part, it is the DHBs that are responsible for providing or funding the provision of health services in their district. Figure 3 shows the map of the DHBs of the main islands of New Zealand.

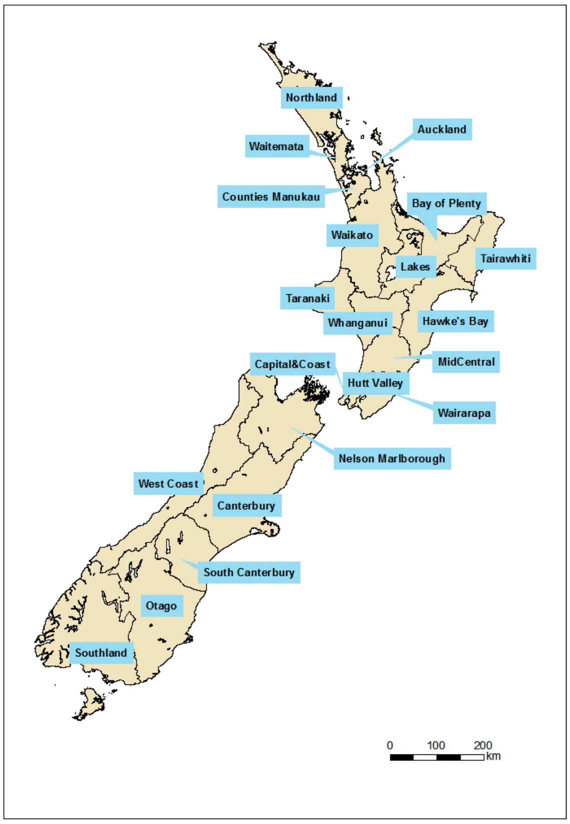


Figure 3 - District Health Boards in New Zealand

Official geographic areas (without the context of health) are Regional Councils, Territorial Authorities, Census Area Units and Meshblocks. The smallest geographical unit, for which official statistical data is collected, is Meshblocks. There are 39,300 Meshblocks with an average population of 110 inhabitants. Census Area Units are an aggregation of Meshblocks of which there are 1,927 (1,777 on the 2 Main Islands) in New Zealand with a median population of 2000 (in the year of 2009). However, within the urban areas the population ranges between 3000 and 5000 habitants (with exceptions to units with for example industrial areas or port areas) (www.stats.govt.nz).

2.2.3 Population

In 2011 there are approximately 4,36 million people living in New Zealand of which 76,8% are of European descendants, 14,9% Maori, 9,7% Asians, 7,2% other Polynesian Pacific Islanders and 0,9% are Middle Eastern, Latin Americans and Africans (MELAA). Some people identified themselves as part of more than one ethnic group (www.state.gov). The ethnic composition per District Health Board can be seen in Figure 4. Most DHBs have a majority of Europeans inhabitants. A majority of Maori can only be found in the North East of the North Island. Besides the Maori proportion is also fairly high in Northland, Taranaki, the Lakes and Hawke´s Bay. The highest proportion of Asians is in Counties Mankuau, Auckland and Waitemata on the North Island. On the South Island Europeans are consistently dominating in all DHBs. The map is based on the Census data from 2006.

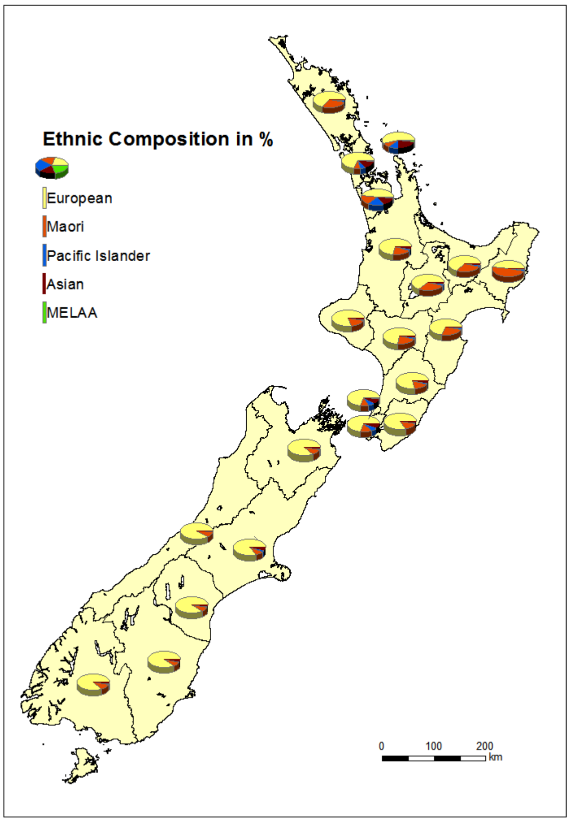


Figure 4 – Ethnic composition in percent per District Health Board in New Zealand

Most New Zealanders (nearly 76%) live on the North Island and about 85% of the population lives in urban areas (www.state.gov). The most populated city is Auckland (1,354,000 habitants) followed by the capital Wellington (389,700) and Christchurch (390,300) in June 2010 (OECD, 2011). Figure 5 shows the density of New Zealand´s population. What can be seen is that most parts have a low density and in particular in the South Island the majority has less than 1 inhabitant per km². Only the urban areas have a more dense population and in Auckland it rises up to nearly 8000 inhabitants per km². The data from the map comes from the New Zealand Census from the year 2006.

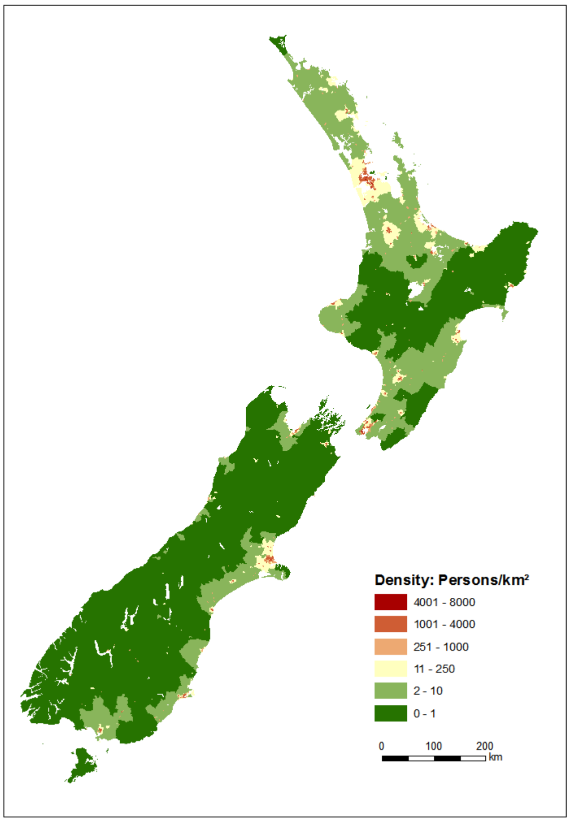


Figure 5 – Population density of New Zealand (persons/km²) in 2006

2.2.4 Economy

The primary and secondary sectors make up about 30% of the Gross Domestic Product (GDP), whereas the majority of the GDP and employment is provided within the tertiary sector. Dairy, sheep and beef farming as well as forestry and fishing are the major income sources within the primary sector, closely related to the secondary industry, which mainly consists of processing these primary products, in addition to machinery/equipment manufacturing and aluminum/steel enterprises. Within the tertiary sector the dominant fields are finance, insurance, property services, transport, education/building and retail (http://www.teara.govt.nz/en/industrial-sectors/1).

2.2.5 Physical Environment

The two main islands (North and South Island) are separated by the Cook Strait and surrounded by the Pacific Ocean (Tasman Sea on the west).

2.2.5.1 Relief

The landscape is characterized by mountainous regions on both islands (Wardle 1991). As Figure 6 reveals, especially on the South Island the mountains are quite dominant and are up to 3700 meters high. The coastal areas are relatively flat. The North Island is in general less elevated, with exception to the central part around Lake Taupo and the region from Taupo to the North East. The data for this map comes from the website www.koordinates.com (DEM 80m) and has been published by Ollivier & Co (License: Creative Commons Attribution 3.0).

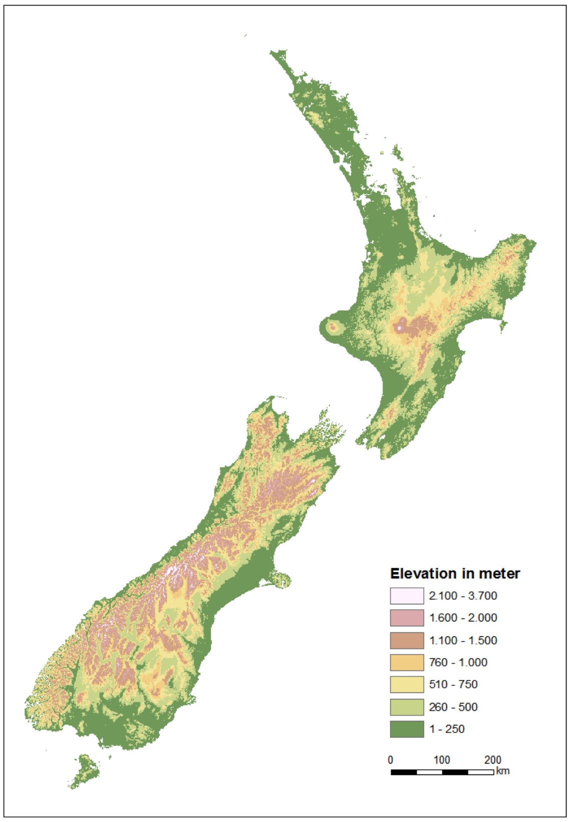


Figure 6 – Elevation of New Zealand

The location at the boundary of the Pacific and Indo-Australian tectonic plates is responsible for this mountainous terrain and also leads to earthquakes as well as volcanic and geothermal activity (http://www.mfe.govt.nz/publications/ser/enz07-dec07/html/chapter2-environment/page2.html). The geothermal areas are situated in the centre of the North Island. The city Rotorua is built on an active geothermal field. Several geothermal bores are located in the vicinity, which cause the emission of the gas Hydrogen Sulfide H_2S, which can lead to a pollution of “H_2S by > 500 parts per billion away from active vents and > 5 parts per million near fumaroles” (Durand & Wilson, 2006). These geothermal areas also have an increased SO_2 concentration (Ministry of Health, 1996).

2.2.5.2 Climate

Due to its location, New Zealand is heavily influenced by the ocean which also results in sudden weather changes in particular throughout the spring (September to November). This appears especially where the land is quite narrow and bordering to both oceans, such as Wellington. In general New Zealand has a temperate (in the South) to a subtropical climate (in the North) (www.state.gov).

Temperature

According to the Food and Agriculture Organization of the United Nations (www.fao.org/ag/AGP/AGPC/doc/Counprof/newzealand/newzealand1.htm) the mean air temperatures varies throughout the year, whereas the influence from the ocean moderates the temperature. Overall, the temperature increases from the South to the North. The far north of the North Island has a mean annual temperature of up to 16°C, but most areas of the North Island have an annual mean of 10 to 14°C (see Figure 7). On the South Island the mean annual temperature overall is 8-10°C, but the mountain areas are much colder and partially have only 2,5°C as annual mean. Temperature decreases not only from North to South by latitude but also with altitude in the mountainous regions. As the subchapter Relief (2.2.5.1) has shown, the South Island is characterized by areas of high altitude. This of course is apart from the latitude, one of the main influencing factors to the temperature and explains the difference between mean annual temperatures in the North and South Island. At the coast of the North Island there is no frost, but towards the inland frost occurs during the winter months, especially on the central plateau. Snow rarely falls below 600 m on the North Island. The South Island being in general colder than the North Island has snow reaching down to 300 m above sea level. As GIS data only mean temperature data for the years 1950 to 1980 was available through the LENZ dataset (which is further described under chapter 3.1.2.1). Figure 7 represents the mean annual temperature in °C, while Figure 8 illustrates the mean minimum temperature for the coldest month.

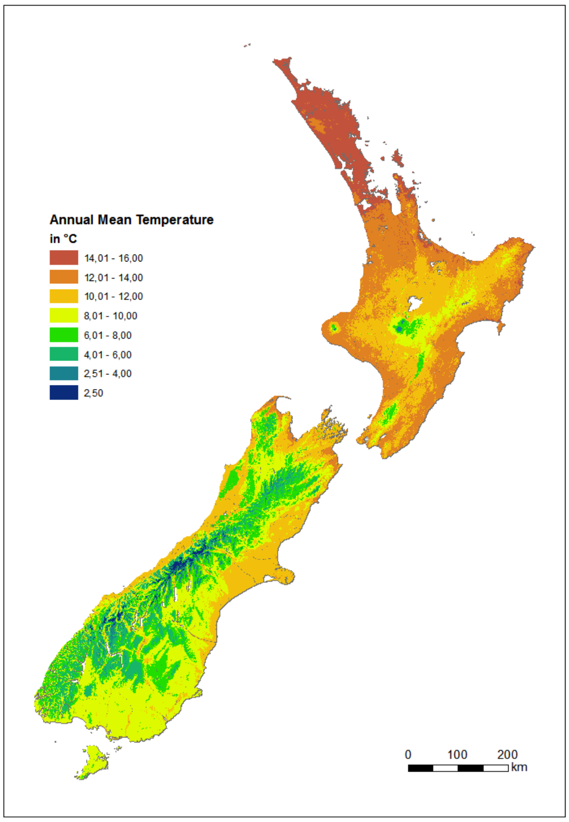


Figure 7 - New Zealand Mean Annual Temperature (°C), 1950-1980

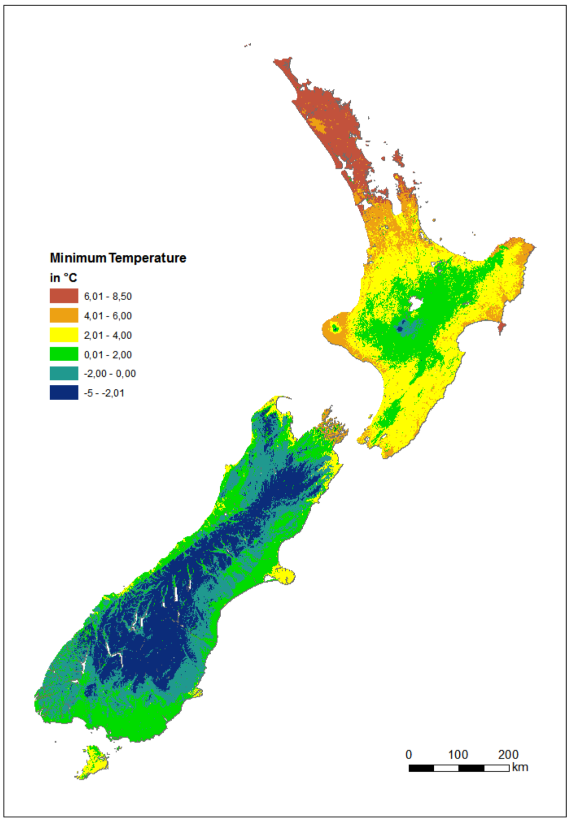


Figure 8 - New Zealand Mean Minimum Temperature of the coldest month (°C), 1950-1980

The sunshine hours are lowest on the south and west coast of the South Island (90-1400 hours per year) and are highest in the northwest of the North Island and the most northern parts of the South Island. The map (Figure 9) is taken from the website of the National Institute of Water and Atmospheric Research (NIWA) (www.niwa.co.nz).

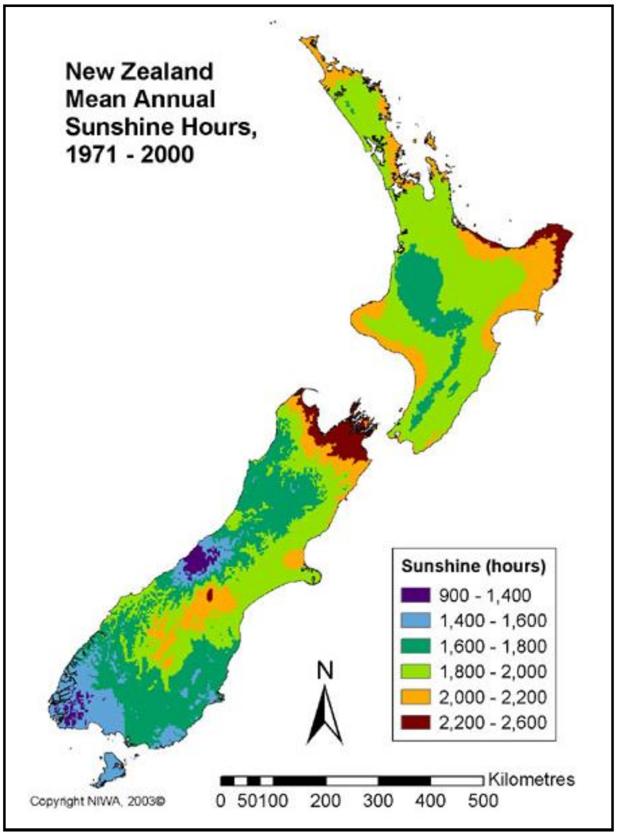


Figure 9 - New Zealand Mean Annual Sunshine Hours, 1971 - 2000

Source: http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview

Rainfall

The mountains, especially on the South Island establish a characteristic pattern of the rainfall, which is high on the west coast due to westerly winds and decreases towards the east coast of the South Island (see Figure 10). Thus the minimum annual rainfall varies from only 300 mm per year in the east in Central Otago to over 8000 mm in the Southern Alps (http://www.metservice.com/learning/nz-climate). Apart from those extremes the rainfall ranges between 600 to 1500 mm in most parts of the country.

Furthermore the amount of rain varies throughout the year. Partially (in the north) the rainfall is twice as high during the winter than during the summer. Only in the southern half of the South Island there is a dominance of summer rainfall, whereas the rest of New Zealand`s mainland has a dominance of winter rainfall (www.fao.org/ag/AGP/AGPC/doc/Counprof/newzealand/newzealand1.htm). Most parts of the North Island have rainfall of at least 1,0 mm at a minimum of 130 days out of the year. The driest areas of the North Island are situated on the east with less than 113 days of rainfall. In comparison the driest parts of South Island have an average of 80 rain days per year. However the very southeast (Fjordland) reaches over 200 days of rain per year (http://www.metservice.com/learning/nz-climate). Figure 10 is a map of the annual rainfall representing the means for the years 1971-2000. The data for the map is from the National Institute of Water and Atmospheric Research (NIWA).

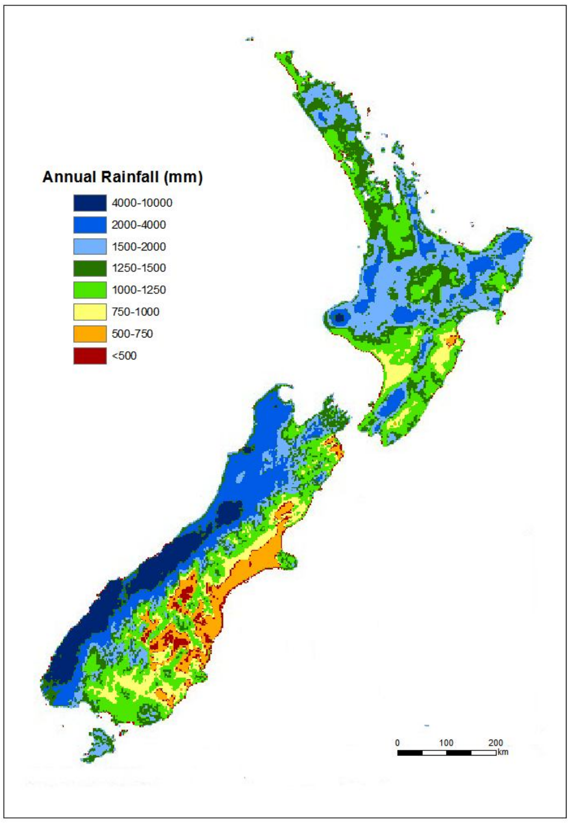


Figure 10 - New Zealand Mean Annual Rainfall (mm), 1971 - 2000

Humidity

In most parts the mean relative humidity lies between 65 to 85%. In the lee of the Southern Alps the relative humidity ranges only from 5 to 30%.

Wind

The wind is mostly coming from the west and causes the previously mentioned higher rainfall on the west coast (www.metservice.com). North of Taranaki the wind is predominantly south westerly. While in the North Island lowest wind speeds occur during summer/early autumn, the South Island has its lowest wind speeds during winter (July/August). In Wellington in particular wind speeds are typically quite high with an average of 173 days of gust (> 60 km/h) per year. Rotorua, in the center of the North Island for example only has 30 days of gust and Nelson, which is on the northern tip of the South Island, has an average of 35 days per year (www.metservice.com). The majority of the coast has predominant sea breezes during the summer.

2.2.5.3 Vegetation

The predominant vegetation in New Zealand is exotic grassland. In the past, the North Island was covered primarily by indigenous forests – the South Island by forest and tussock. However today these can be mainly found on the west coast (South Island) and the central hilly and mountainous parts of the North Island (http://www.teara.govt.nz/en/soils-and-regional-land-use/1). Because of the heavy rainfall on the west coast of the South Island, rainforest can be found on the western side of the mountains (www.metservice.com). Figure 11 is a map that was created with data from a dataset (Land Cover Database) from the Ministry for the Environment which is available online free of charge (www.koordinates.com). The map shows the 8 main land cover classes. More detailed information about this dataset can be found in chapter 3.1.2.1 “Environmental Variables”, as the land cover also serves as independent variable for the analysis. The map show that especially on the North Island grassland is the most dominant land cover class, with a higher dominance of forests east/north east of Lake Taupo in the center. On the west coast of the South Island forest is the predominant land cover. The mountainous central area of the South Island is barely or lightly vegetated in the high altitudes and further east grass land is mostly prevalent.

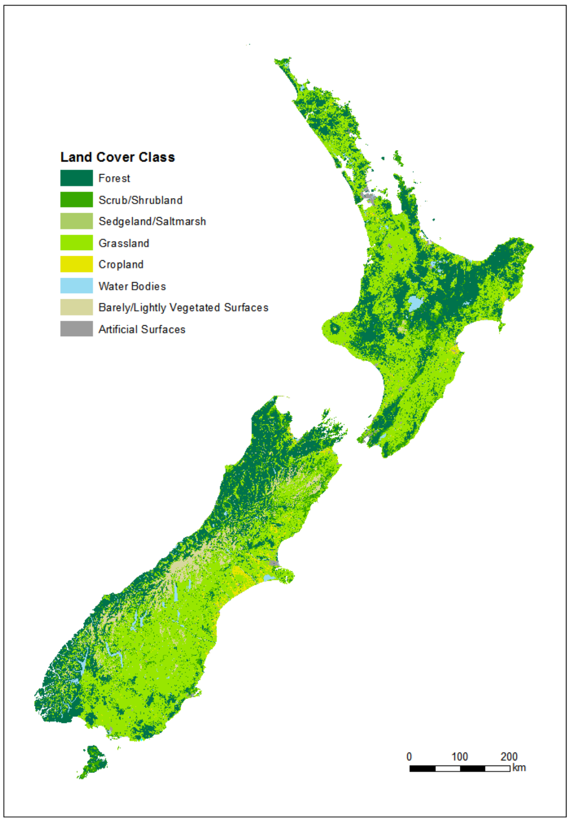


Figure 11 - Land cover classes of New Zealand

2.2.5.4 Air Quality

Overall New Zealand is considered to have low air pollution in most parts of the country. The Ministry for the Environment of New Zealand also confirms that at most locations the air quality is good in New Zealand. Nevertheless Auckland (mainly through traffic and heating) and Christchurch (mainly through industrial emissions) are both an exception of the general picture (Scoggins *et al.*, 2001). Besides, emissions became higher over the last 20 years. The emissions of CO_2 for instance have increased by 44,9% (OECD, 2011). Because of the use of coal and wood for home heating and also the emissions from transportation some parts are affected by air pollution. About 30 locations are found within New Zealand where the air quality is affected by high emissions, in which roughly 53% of the population lives (http://www.mfe.govt.nz/publications/ser/enz07-dec07/html/chapter7-air/). In general the air pollution is worse during the winter months, partially because of heating with coal and wood (PM_{10} particulates are emitted). Auckland is in particular affected by high PM_{10} emissions (http://www.mfe.govt.nz/publications/ser/enz07-dec07/html/chapter7-air/).

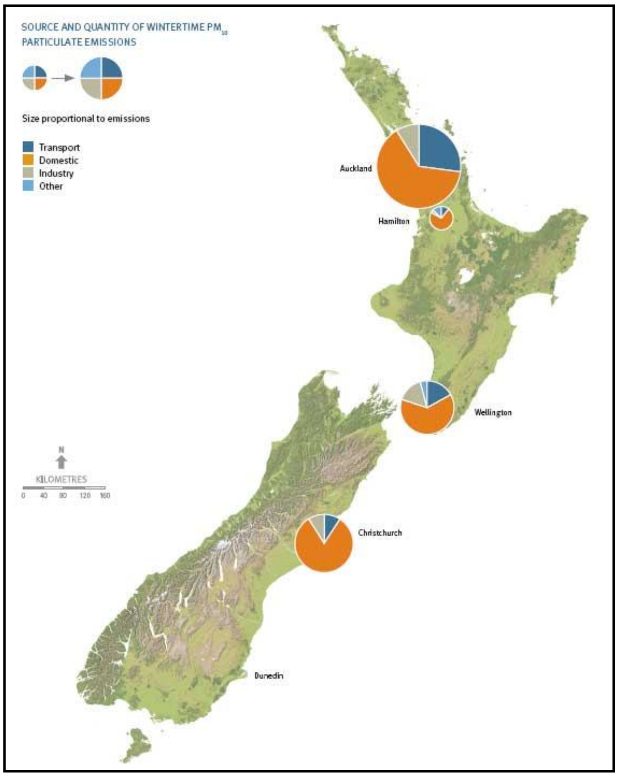


Figure 12 - PM_{10} emissions at New Zealand´s main population centers

Source: http://www.mfe.govt.nz/publications/ser/enz07-dec07/html/chapter7-air/figure-7-6.html

The levels of SO_2 are low in most countries and have been decreasing since the 1980s. The Ministry for the Environment points out, that the areas around the Marsden Point Oil Refinery, situated in Whanagrei (Northland) are an exception to the general picture (http://www.mfe.govt.nz/publications/ser/enz07-dec07/html/chapter7-air/index.html). As previously mentioned also the areas in the vicinity of geothermal bores (found in the center of the North Island) are affected by an increased SO_2 concentration. As New Zealand has geothermal activity, a focus has to be put on the occurrence of H_2S as well. As mentioned earlier, in particular the centre of the North Island around Taupo (Volcanic Zone Taupo) and Rotorua are areas where high geothermal activity occurs and where geothermal energy is used. Studies have focused in particular on the health effects due to H_2S levels in this area (Durand & Wilson, 2006 and Hinz, 2011).

Especially the Auckland region (home to 1/3rd of New Zealand´s population) registers high levels of PM_{10} due to high traffic and in winter time due to heating with coal and wood. Because of the intense traffic, Auckland also builds an exception to the overall countrywide acceptable levels of NO_2 (http://www.mfe.govt.nz/publications/ser/enz07-dec07/html/chapter7-air/page3.html).

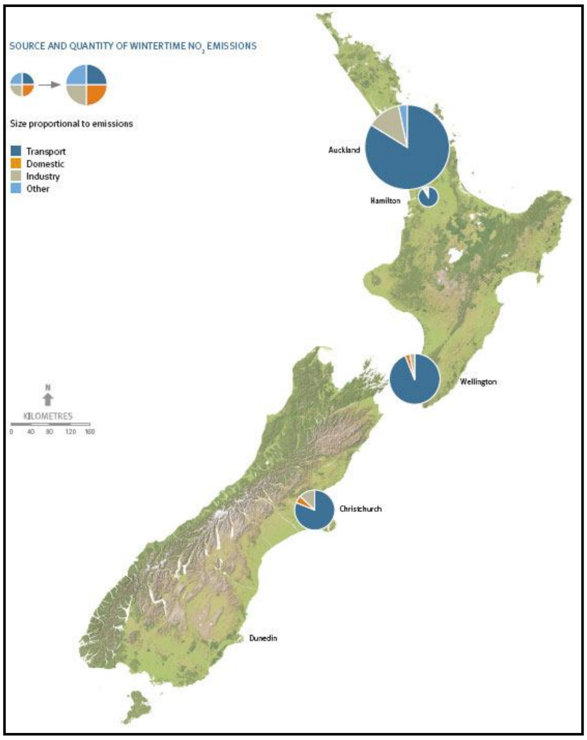


Figure 13 - NO_2 emissions in New Zealand´s main population centers

Source: http://www.mfe.govt.nz/publications/ser/enz07-dec07/html/chapter7-air/figure-7-8.html

Sulphur dioxide levels declined since the 1970s and 80s, since coal and heavy fuel oils were used less and less in Auckland. Only in the 1990s a minor increase took place because of imported diesel vehicles (http://www.mfe.govt.nz/publications/ser/enz07-dec07/html/chapter7-air/page3.html).

2.3 Asthma in New Zealand – Literature Review

In the 19th century New Zealand went through two drug-induced mortality epidemics. The first epidemic was in the 1960s, in which the death rates increased drastically. The reason for this increased asthma mortality is most likely the use of the beta-agonist aerosol "isoprenaline forte" (Holt & Beasley, 2001). A second mortality in the 1970s was brought into context with the use of another drug "fenoterol", which had heavy side effects. The death rate was around 4,0 per 100,000 during the late 1970s (Crane *et al.,* 1992). Once feonterol was restricted the death rates decreased markedly (Ministry of Maori Affairs 1991).

After the last mortality epidemic of asthma in the second half of the 19th century the death rates of asthma in New Zealand have remained low at around 0,5 per 100,000 (Holt & Beasley, 2001). Nevertheless, asthma prevalence in general is rising constantly and brings up the question what reasons cause the increase of the asthmatic population. Even though generally speaking New Zealand has a high rate of asthma, there are some major differences between geographical regions and also between social statuses.

Age and gender

The rate of asthma in New Zealand varies between age groups and gender. During childhood, asthma is more common for boys compared to girls (Wickens *et al.,* 2001). During adulthood however more women than men tend to have asthmatic symptoms (Ministry of Health, 1996). The report of the Ministry of Health New Zealand about the National Health Survey of 1996/7 (Ministry of Health, 1999) states that within the age group of 15-44 the total rate of probable asthma is 15,5%. The rate for men is 12,9% while women have a rate of 18,0%. Kimbell-Dunn *et al.* (2000) also states that hospitalization rates decrease for males with age, whereas females show increased asthma prevalence between 15-44. Also death rates were higher for the period of this study (1976-1995) for women aged 15 and older.

This observation is quite typical for other countries as well. It is common that during childhood boys tend to have more asthma while during adulthood the pattern is reverse. At the same time there is an often observed decrease of asthma as of puberty. The reason for both disparities of asthma rate for female/male during childhood/adulthood and the abate of asthma during puberty are not clear yet (Nicolai *et al.,* 2001).

Ethnicity

Various studies and also statistics from the past have shown an inequality of asthma among ethnicity in New Zealand (Wickens *et al.,* 1998; Mitchell, 1991; according to Ministry of Health, 1999). According to Holt & Beasley (2001), Maori and Pacific Islanders are more affected than Europeans and Asians. In 1996/7 18,6% of Maoris compared to 15,6% of Europeans are asthmatics. The highest rate in 1996/7 was observed for Maori women from age 15 to 44 (20%) (Ministry of Health, 1999). Ponmare *et al.* (1992; according to Ministry of Health, 1999) also reported that Maori children seem to have more severe asthma compared to non-Maori children, possibly due to lifestyle such as exposure to tobacco smoke and allergens and at the same time “poorer access to health services and preventive medications” (Ponmare *et al.,* 1992, according to Ministry of Health, 1999).

Social Status

Furthermore a significant relationship between family income and rate of probable asthma is apparent. The National Health Survey of 1996/7 shows that the highest rate of probable asthma occurs for persons who live in families with less than 20,000 NZD (21,8%). For both 20,000 to 30,000 and 30,000 to 50,000 the rate is at 15,8%, whereas family members with an income of 50,000 NZD have the lowest rate of 13,5% (Ministry of Health, 1999). This might be plausible due to worse living conditions, less consumption of fruit and vegetables and an insufficient access to health care. The New Zealand Deprivation Index, ranging from 1 to 10 with 10 being the most deprived area and 1 being least deprived, has also shown that high asthma prevalence is more likely in the most deprived areas of New Zealand (Salmond, 1998). The Index is composed of several variables that indicate the state of wealth and deprivation. The attributes included are income, owned home, support for elderly people, employment, qualification, living space, communication (access to telephone) and transport (possession and access to a car) (Salmond *et al.,* 2007). An indirect relation to why lower socio-economic families suffer more often of asthma can be through higher dust mite levels in households (Sears *et al.,* 1989). At the same time, the education level seems to influence the prevalence of asthma in New Zealand. The rate among people with no qualification is 17,2% whereas the rate of asthma in people having post-school education is only 14,4% (Ministry of Health, 1999). An indirect influence of the level of qualification on prevalence of asthma could be that people with higher education often have a better economic situation. The more favourable economic situation enables better living conditions.

Allergens

In international comparison New Zealand´s households appear to be more burdened by mould than in many other countries, whereas low-income families are especially affected. Results from the national survey show, that mould is present in over a third of New Zealand homes (Wilson *et al.,* 2007). Wilson also notes that fungal spore levels are most elevated in New Zealand’s autumn, which correlates with the time of the year with the highest rate of asthma hospitalisation for patients aged 5 to 14 and 15 to 44. A study about damp and cold housing in pacific family households reported that 37% of the households had problems with damp/mould (Wilson *et al.*, 2007). Correlation between maternal asthma and dampness/mould has been observed in a study from Butler (2003; according to Wilson *et al.,* 2007). Sears *et al.* (1989) mentions in his study about risks of sensitivity to grass pollen (and also other allergens) that it is likely, that every child in New Zealand has been exposed to grass pollen due to the extensive grasslands of the country and also the fact that even in cities, parks and own lawns are very common in New Zealand.

Seasonal variance

Bates (1990) (according to Ho 2007) states that there are seasonal differences of asthma attacks in New Zealand. This might indicate the influence of climate for asthma in New Zealand. Both direct influence and indirect influence (for example on damp/mould or presence of pollen) can be a reason for the variation. As noted under chapter 2.2.5.4 “Air Quality”, heating during the winter, in particular when coal and wood are used, air pollution is more intense during that time of the year. In a study where asthma hospitalization and mortality data was observed for seasonal variance in different age groups over a 18 year period for hospitalization (1978-1995) and over a 20 year period for death (1976-1995) distinct variations were found. The Wellington Asthma Research Group found that for hospital admission there was a clear peak in autumn (April-June) and on the other hand a distinct decrease for summer (January/February) (Kimbell-Dunn *et al.,* 2000). For mortality the seasonal variance varies more amongst age groups. For the age group 5-14 peaks for asthma mortality were found for the months: December to February, May and September. These overlap with the primary school holidays at the time. Possible explanations are according to Kimbell-Dunn *et al.* (2000) the lack of supervision (medical, family or school), another routine and limited access to medical care. For the age group 15-44 the peak for asthma mortality was between December to March and for the age group of 45 and older it is between July through September. In all cases significance was observed. The age group of 45 and older thus has the same peaks for both mortality and hospital admissions. A plausible explanation for the increase during winter months is the higher risk of respiratory tract infections (Kimbell-Dunn *et al.*, 2000).

3. Data and Methods

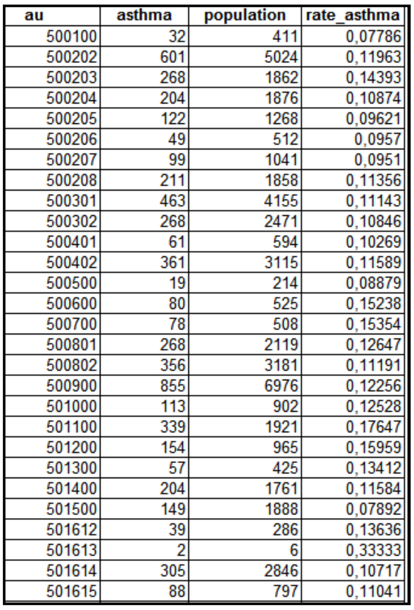
3.1 Data

In the following subchapters the data chosen for the analysis is presented. Both environmental and social characteristics are used to search for explanatory variables for the distribution of medicated asthma rates. The details about the source and preparation of the data are described under the subchapter “Independent variables” (3.1.2). Some variables, such as temperature for example are less suitable for the detailed analysis. Therefore some factors are used for the national scale only, whereas others are only used for the regional analysis. After all the environmental variables (3.1.2.1) and social characteristics (3.1.2.2) a summary with all variables and the area for which they were applied is given (chapter 3.1.2.3). The programs used for the preparation are the GIS software ArcGIS 10, the statistic software SAS 9.3 and Microsoft Excel 2007.

3.1.1 Asthma prevalence – the dependent variable

The prevalence of asthma is difficult to grasp, since there is not a single objective test. Questionnaires always present a sample only. To actually get the full picture of a type of measuring asthma prevalence, this study uses medicated asthma as indicator, which includes not only hospital admissions but also individuals who purchased preventive and treating asthma medication. Thus it includes all treated asthma for New Zealand available on Meshblock and Census Area Unit level. In this case medicated asthma as total number of persons and rate per CAU for the years from 2009 to 2010 are considered. The most recent available data is used, since at the time when the study was carried out, 2011 data was not available yet. The table has the geographical unit as unique identifier and in addition the columns (attributes): total number of persons who have medicated asthma, the population (of the geographical entity) as well as the medicated asthma rate.

Table 1 – Extract from Excel table of Asthma rate per CAU



au	asthma	population	rate_asthma
500100	32	411	0,07786
500202	601	5024	0,11963
500203	268	1862	0,14393
500204	204	1876	0,10874
500205	122	1268	0,09621
500206	49	512	0,0957
500207	99	1041	0,0951
500208	211	1858	0,11356
500301	463	4155	0,11143
500302	268	2471	0,10846
500401	61	594	0,10269
500402	361	3115	0,11589
500500	19	214	0,08879
500600	80	525	0,15238
500700	78	508	0,15354
500801	268	2119	0,12647
500802	356	3181	0,11191
500900	855	6976	0,12256
501000	113	902	0,12528
501100	339	1921	0,17647
501200	154	965	0,15959
501300	57	425	0,13412
501400	204	1761	0,11584
501500	149	1888	0,07892
501612	39	286	0,13636
501613	2	6	0,33333
501614	305	2846	0,10717
501615	88	797	0,11041

The *shapefile* for Census Area Units is provided by the Ministry of Health. It includes the number and name of each CAU, the actual population, the area and population density (for the year 2006). This file serves as the foundation to combine the spatial units (CAU) with the table containing the asthma rate. A separate pivot table with proportion of asthma per ethnicity, gender, age group (of 5 years) and deprivation Index for New Zealand (without geographical substructure) is also created. The table was extracted by Craig Wright, employee of the Health & Disability Intelligence Unit at the Ministry of Health New Zealand. The advantage of using Tracker as opposed to hospital admissions only, like several studies did, is that also visits at the General Practitioner and medication bought from pharmacies are considered, which gives a more complete picture to the prevalence of asthma (this variable is mapped in subchapter 4.1 for both New Zealand and Auckland area).

3.1.2 Independent Variables

To find out about correlation between asthma prevalence (medicated asthma) with possible causes of asthma, factors of the physical environment and social variables within the CAUs are examined.

3.1.2.1 Environmental variables

Climate

All climate data is only used for the national analysis. From the Land Environments New Zealand (LENZ) dataset, various dates are available and accessible free or charge under the Creative Commons Attribution 3.0 New Zealand License. The data is provided by the organization Landcare Research. For this study the factors that have been included are:

- Mean Annual Temperature (in °C) (see Figure 7 under chapter 2.2.5.2)
- Mean Minimum Air Temperature of the coldest month (in °C) (see Figure 8 under chapter 2.2.5.2)
- Water Balance Ratio: The Landcare Research Team calculated the ratio using monthly estimates of mean daily temperature, mean daily solar radiation, and mean rainfall. Landcare Reseach retrieved the data from summaries of climate observations that were published by the New Zealand Meteorological Service (1950-1980) (http://lris.scinfo.org.nz/layer/93-lenz-monthly-water-balance-ratio/metadata/). The ratio of rainfall to evaporation was calculated for each month, after which the average of all twelve ratios was computed as the final value (Leathwick *et al.*, 2002)

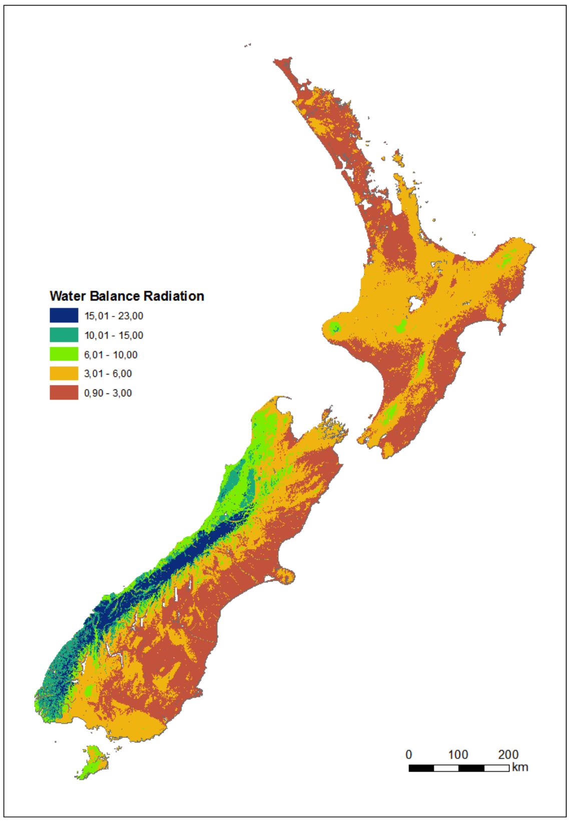


Figure 14 – New Zealand Water Balance Ratio

The calculated Water Balance ratio ranges between the lowest value of 0,9 and the highest value of 22,8 (west of the South Island). The overall mean for New Zealand is 4,6).

- Humidity: Mean October vapor pressure deficit in kPa ranging from 0 to 0,62 kPa. The lowest values can be found throughout the west coast of the South Island, where rainfall and Water Balance Radiation are the highest. The highest deficit on the other hand can be observed on the north east coast of both North and South Island. The reason why Landcare Research, who created LENZ, picked the data for the month of October, is because this is when westerly winds are most persistent, which causes strong geographic variation across New Zealand.

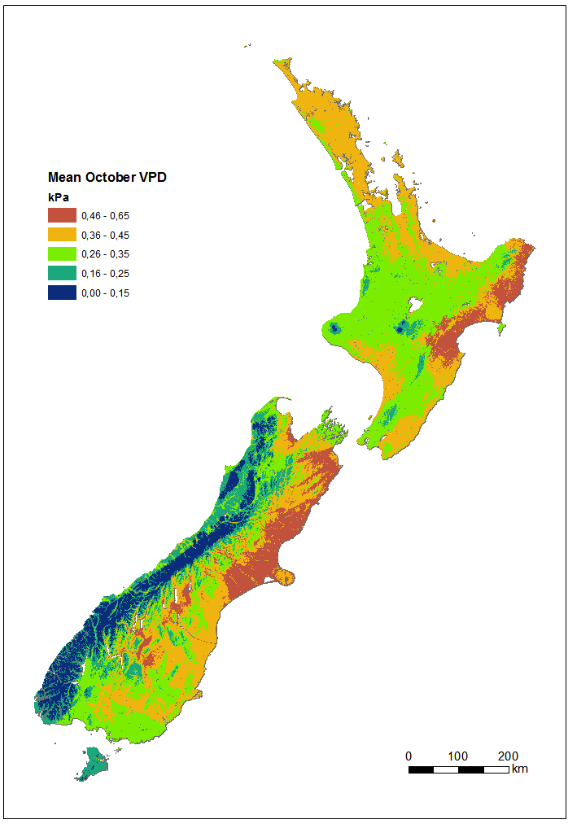


Figure 15 – New Zealand Mean October Vapor Pressure Deficit (kPa)

Furthermore rainfall and wind speed data were gathered from other sources:
To analyze the relationship between rainfall and medicated asthma rate, the rainfall map from the National Institute of Water and Atmospheric Research (http://www.niwa.co.nz/gallery/climate-nz-rainfall-1971-2000) was first georeferenced in ArcGIS 10. Afterwards an image classification was carried out in ArcGIS 10. Once appropriate samples within the Training Sample Manager were collected the Maximum

Likelihood Classification was executed. The resulting map (Figure 10) was also utilized in chapter 2.2 “The area under investigation: New Zealand” to characterize the climate (subchapter 2.2.5.2). To use the data for the analysis, the raster was converted into a polygon and then joined (spatial join) with the CAU layer.

Wind speed information is gathered through the CliFlo Service from the NIWA website. The National Institute of Water and Atmospheric Research (NIWA) provides a free online service with access to New Zealand´s National Climate Database (www.niwa.co.nz). Both raw data and summaries are available ranging from about 6500 stations, of which 600 are currently open. Not all of these stations measure wind speed data though. For this study purpose, the annual means of 2009 for all stations throughout New Zealand that hold wind speed data (m/s) is extracted through the website. The 130 stations that have wind speed data for the year 2009 are projected in ArcGIS and then joined with the wind speed data (in m/s). Inverse Distance Weighting Interpolation is executed to receive a raster, which then is converted to polygons. These polygons which contain the wind speed are combined with the CAU layer through a spatial join (calculating average wind speed, maximum wind speed and the variance).

Elevation

In addition to the variables describing climate, the average elevation per CAU is used for this study. Through the LENZ file also elevation data is accessible as polygon *shapefile*. After a spatial join with the Census Area Unit *shapefile* the average elevation per CAU is available.
A map of the relief of New Zealand can be seen under chapter 2.2.5.1 (Figure 6). Elevation was also only applied for the national analysis.

Slope

Furthermore the LENZ file provides information about slope, which was also included in the analysis. The same means of preparation was applied as for the other LENZ data. The values range from 0 to 42,9.

Urbanization

From the dataset of the Ministry of Health a *shapefile* was used, which contains the degree or rurality in its attribute table. However this is for on Meshblock level. Therefore the first step to use the urbanization data is to execute a spatial join between the Meshblock data and the

CAU data, where the average urbanization rate of all the Meshblocks within one Census Area Unit is determined and added to the attribute table of the Census Area Unit *shapefile*. One field describes the class: “Other (Inland Water, Inlet and Oceanic)”, “Other Rural”, “Rural Centre”, “Minor Urban Area”, ”Secondary Urban Area” and “Main Urban Area”. Another field contains the numerical pendant using the categories from 1 to 6 (1 represents “Main Urban Area” and 6 stand for the category “Other (Inland Water, Inlet and Oceanic”). The category 6 is not relevant for this study, and therefore was excluded from the analysis, since these areas have no population and therefore no asthma prevalence to represent. Urbanization is only used for the national analysis.

Land Cover

The Ministry for the Environment has released (under the license: Creative Commons Attribution 3.0 New Zealand) a database with polygon features of overall 43 land cover classes (available through http://koordinates.com/layer/1072-land-cover-database-version-2-lcdb2/). The first order classes are: Artificial surfaces, Bare/Light Vegetated Surfaces, Water Bodies, Cropland, Grassland, Sedge land Marsh, Scrub/Shrubland and Forest. A map of these classes can be seen under chapter 2.2.5.3 Vegetation (Figure 11). Each of them has subcategories such as Built-up Area, Urban Parkland/Open Space, Surface Mine, Dump and Transport Infrastructure for the case of “Artificial Surfaces”. To make use of the data for the analysis, they had to be prepared. First of all the Overlay tool “Identity” within the software ArcGIS 10 was utilized for each land cover class of interest individually to create a file for each land use class that splits the polygons according to the Census Area Unit borders. The second step is to add a field within the attribute table, which contains the area of each polygon of the land cover class under investigation (in hectare). Next, a summary statistics is built, which sums up all of the patches within each CAU to calculate the entire area of each land class individually per Census Area. The output table is then joined with the CAU *shapefile*. With the output *shapefile* the density can be calculated to receive the percentage of each land class category by Census Area Unit. Besides a frequency is automatically calculated, which is interesting when it comes to Mines and Dumps subclass, not so much with the other land cover classes, where the size or density is more relevant. The subcategories Mines & Dumps and Pine Forest (Closed and Open Canopy) are also tested apart from the 8 first order classes. The reason why Pine Forest areas are selected is because pines are a common allergen (www.allergyclinic.co.nz). The land cover variables were only used for the national analysis.

Air Pollution

To analyze the relationship with air pollution, a dataset from the “Health and Air Pollution in New Zealand” (HAPNZ) is utilized, which is carried out through the Health Research Council of New Zealand with the Ministry for the Environment, Ministry of Transport, New Zealand Transport Agency, the Ministry of Health and the legacy Auckland regional Council. After the first study was done in 2007, an updated version was recently published in March, 2012. PM_{10}, as well as $PM_{2,5}$ data is collected on various monitoring sites throughout the country. The monitoring is organized the Regional Councils, which is why not all areas have an equal coverage. The available data is for the years of 2006 to 2008. Estimates are made for each CAU based on number of houses using wood and coal, vehicle kilometers travelled estimates and real/proxy industrial emissions data. The primary purpose of the study is to correlate various health concerns with air pollution. A Health Effects Model can be downloaded from the website (www.hapinz.org.nz) as Microsoft Excel file, which contains the data about total annual average PM_{10} and $PM_{2.5}$ emissions per CAU including information about the sources (in percent for natural sources, industry, domestic emissions and outdoor burning). With the “CAU name” field of the file a join can be performed in ArcGIS with the spatial CAU layer. Including other air pollution variables like H_2S or SO_2 in a nationwide analysis is difficult, since no standardized measurements over the entire study area exist. The air pollution data is used for national analysis only.

Density streets

Since traffic is one of the main reasons for increased air pollution, in particular in relation to CO, CO_2 and also NO_2 emissions, the density of all streets per CAU was used to examine the relationship with traffic volume and medicated asthma. Useable data with centerlines of all roads is available on the website www.koordinates.com. The information of the file includes speed limit of the road and the type (Residential, Collector, Arterial, Principal and Major Highway). Ferguson (2004) quotes that past studies showed significant correlation of asthma morbidity with high traffic volume. The same techniques (Identify, Summary Statistics and Join) that were applied for the Land Cover data are utilized for the streets. This road data was used for the national analysis.

Location of Highways

For the larger scale/regional analysis, not the density of streets was applied, but the location of highways. The distance to main roads from the residence neighborhood can be relevant for asthma. The road types that are of high interest are thus principal and major highways. The roads *shapefile* was clipped first to the Auckland study area extension, before selecting the two road types (major and principal highways) in order to create a *shapefile*. Brunekreef (1997) found an association between children living within less than 300 m to motorways and measured lung function. According to Ferguson (2004) it is unlikely that someone is still affected by traffic pollutants when living further than 1000 m from a main road. Morgenstein (2007) for example used circular buffers ranging from 50 to 5000 m. With these indications the buffer zones chosen for road distance for this study are: 100, 250, 500 and 1000 meter.

Other factors

In addition, thanks to the LENZ data, the relationship of asthma to landfills (which are sources of H_2S as well as other pollutants) and geothermal bores is examined. *Shapefiles* for both are available online free of charge from the website www.koordinates.com and contain the variables as polygons. This data is only used for regional scales (Auckland region in case of landfills/ Taupo Volcanic Zone for geothermal bores).

3.1.2.2 Social Characteristics

Census data

To receive information about social variables the census for New Zealand offers an official data source with statistics about the population and dwellings. By law, the census has to be held at least every 5 years (www.stats.govt.nz). Through the official statistics website of New Zealand, censuses are available for various scales as raw tables, quick stats and maps. The smallest available spatial subdivisions are Meshblocks. Furthermore the statistics are attainable on Census Area Units subdivisions, which are used for this study. The national dataset is available named “Meshblock dataset”, divided into the 17 regions, all of which have sheets for Census Area Units as well. The relevant information which is used for the analysis process is extracted from the census of 2006. Multiple variables of the census are considered as potential influencing factors of asthma: age group (in a 5-year span) and ethnicity as total numbers. For all of the mentioned variables the percentage is manually calculated in Excel. The number of children per household and the number of bedrooms is used, too. For children the classifications available are: “no children”, “1 child”, “2 children”, “3 children”, “4 children”, “5 children” and “6 or more children”. For bedrooms the census has data as “bedrooms per household” for each individual: “1” to “7” and furthermore “8 or more bedrooms”. Also mean and median number of bedrooms per household for the CAU is considered. Besides, the census reveals detailed information about qualification and education. Available are total numbers for each level, which means the census differentiates between no school qualification, all four high school levels and various post-secondary levels (postsecondary 1-3, postsecondary 4, diploma 5, diploma 6, bachelor, postgraduate, master and doctorate). This classification seems to be too detailed for the purpose of this analysis. Therefore it is summarized to “no qualification”, “high school”, “post secondary school”, “diploma”, “bachelor”, “postgrad & master”, “doctorate”. There are several indicators for income and employment available from the census 2006. First, there is income for individuals ranging from “less than 5000 NZD” up to “more than 50,000 NZD”. Besides income per family is extracted which is divided into six groups: 0-20,000 NZD; 20-50,000 NZD; 50-70,000 NZD; 70,000-100,000 NZD and over 100,000 NZD. For employment status there are the categories “full-time employed”, “part-time employed”, “unemployed” and “not in labor force”. In addition the means of travelling to work can be used from the census data. The available categories are: “work from home”, “not go to work”, “private vehicle”, “company vehicle”, “passenger”, “public bus”, “train”, “motorbike”, “bicycle”, “walk”, “other”, “not known”. Just like for the other attributes in the census data the information is given through total number of persons. Thus a percentage for each group was computed, while some fields were put together: private vehicle, company vehicle and passenger in one of either were joined together (as “traveling to work by car”). The same applies for walking and using a bicycle as “non-motorized”. The remaining characteristics were treated individually. Besides the New Zealand Deprivation Index is extracted indicating the relative deprivation (from 1 to 10) of each CAU. The type of heating as discussed earlier can be of relevance for developing asthma and has therefore been included in the analysis. The census distinguishes between “electricity”, “mains gas”, “bottled gas”, “wood”, “coal”, “solar power”, “no fuels used in this dwelling”, “other fuels” and “not elsewhere included”. This allows a division into heating types that may harm the respiratory tract and increase the probability for asthma or on the other hand neutral/positive types of heating regarding to asthma. The negative ways of heating in this case are mains gas, bottled gas, wood, coal and other fuels, opposed by the “positive” ways using solar power, no fuels and electricity. The classification “not elsewhere included” has to be ignored for the validation, since it is not clear whether there may be any harm for the respiratory tract or not. For the national scale analysis also population density is examined, as the density varies highly throughout the country as Figure 5 under chapter 2.2.3 has shown. The information about density is from the Census 2006 and was included in the CAU *shapefile* from the Ministry of Health.

Domestic heating emissions

The National Institute of Water and Atmospheric Research created a dataset of domestic fire emission, which is used for both small scale as well as national scale for the analysis methods. Coal and wood emissions from domestic households are specified by Pm/g emission per day per Census Area Unit and also declaring the total number of households within the CAU, that use wood or coal for heating/cooking. With the information about the size of each CAU the PM/g per ha is calculated. Certainly domestic heating emissions could count as an environmental variable as well - since it stands in relationship to housing conditions it was hereby included for social characteristics. Besides for the Auckland region only a social characteristics model was formed and therefore domestic heating emissions had to be part of the social model. All the Census data was applied for the national analysis and the regional analysis of Auckland.

The variables were collected from each region and brought together into a table, which contains all the CAUs of New Zealand as a master set for the census variables and the domestic heating emissions, which are possibly influencing asthma.

3.1.2.3 Summary of all Variables

All the variables that were explained in the two previous subchapters are listed within Table 2 to summarize them and give an overview. Furthermore the area of study is noted, too.

Table 2 - Summary of variables used and their area where applied to

Environmental Variables		Social Variables	
Climate (Mean Annual Temperature, Minimum Temperature, October VPD, Rainfall, Wind Speed)	National Analysis	Age	National Analysis Auckland Region
Elevation	National Analysis	Ethnicity	National Analysis Auckland Region
Slope	National Analysis	Number of Children	National Analysis Auckland Region
Urbanization	National Analysis		
Land cover	National Analysis	Number of Bedrooms	National Analysis Auckland Region
Air pollution	National Analysis	Education	National Analysis Auckland Region
Street Density	National Analysis	Income (Personal & Family)	National Analysis Auckland Region
Highway Location	Auckland Region	Employment Status	National Analysis Auckland Region
Landfills	Auckland Region	Means of travelling to work	National Analysis Auckland Region
Geothermal Bores	Taupo Volcanic Zone	NZ Deprivation Index	National Analysis Auckland Region
		Type of Heating	National Analysis Auckland Region
		Domestic Heating Emissions	National Analysis Auckland Region
		Population Density	National Analysis

3.2 Methods

3.2.1 Literature Review

The topic requires comprehensive literature review about principles of asthma, including global distribution, potential causes and gaps in science and knowledge about the disease. Numerous studies have been accomplished to gain evidence about causes, effects and characteristics of the disease. This allows the selection of suitable explanatory variables. Furthermore the area under examination - New Zealand - with its geography, physical environment and the population is part of the literature review. Scientific articles as well as books and the internet serve as information source and indication for selected variables and background information. Finally also tutorials for the tools and software used, available through the internet and as books (in the case of SAS) are taken as additive source.

3.2.2 Data preparation

After gathering the information and narrowing down possible explanatory variables, data is collected through internet research, contacting official institutions (city council of Auckland, Ministry for the Environment) as well as researchers (Simon Hales) and staff from asthma research facilities for tips, data and suggestions. Fundamental data, like boundaries, oceans, roads and more were already on the computer network of the Ministry of Health of New Zealand.

The collected data has to be prepared and brought into the correct format for the analysis process. For the regression analysis the variables have to be in *shapefile* format. Attribute data which is downloaded as Excel dataset from the official statistics website New Zealand (www.stats.govt.nz) is transformed, so that the table can be joined to the spatial feature data in ArcGIS. For that purpose “Unique Identifiers” need to be adjusted so that a “spatial join” is possible. The content of the identifier has to be exactly the same so that the correspondent spatial entity receives the information of the data table. As asthma prevalence the indicator medicated asthma was considered. Using the statistical program SAS (Statistical Analysis System), which was installed at the computers of the Ministry of Health office in Wellington, the rate of asthma per spatial unit was extracted with the help of Craig Wright (of the HDI department, Ministry of Health, New Zealand).

3.2.3 Disease Mapping

Diseases can be visualized on a map by either point or polygon data. Points symbolize cases, while areas stand for the rate of the disease for this particular area. There is no explanatory information given with disease maps (Moore & Carpenter 1999). However this step is important in order to examine the distribution of the disease and gain first visualized impressions. In this work asthma will be mapped both on a national scale and on a regional scale for Auckland region as choropleth maps as the variable asthma is available as rates per Census Area Unit. The classes are determined by natural breaks and where necessary rounded. This has the effect that the classes are not equally big, unless the natural breaks happened to be this way.

3.2.4 Analysis Process

After the general and purely visual outcome from the disease mapping approach, further investigation is done through spatial analysis methods. After the spatial pattern analysis, which gives information about clustering in both the Auckland region and also New Zealand as a whole, correlation analysis and regression analysis serve as methods to examine the relationship between medicated asthma rates and the independent variables. First, the Auckland region is the focus when filtering suitable risk factors. After the relation of asthma prevalence with each variable is tested, the explanatory variables which show a connection to asthma are put together in a model (see regression analysis). This model is then also applied on a national scale to see whether the same variables that are suitable on a regional scale are appropriate for the national scale analysis as well. Furthermore some of the variables (climate) are only tested on national scale.

3.2.4.1 Spatial Pattern Analysis

In order to explore and analyze the pattern of the asthma prevalence, a spatial autocorrelation tool is applied. The first step for the analysis is to perform a global cluster analysis, which shows whether spatial autocorrelation appears in the entire area. The pattern can be dispersed, random or clustered. A z-score is computed, indicating the degree of clustering. The null hypothesis states that there is no spatial clustering. Using a 95% confidence interval means that the null hypothesis cannot be rejected when the z-score lies between +1.96 and -1.96. In that case the pattern would be random (http://help.arcgis.com). The tool used to perform the global cluster analysis is the global Moran´s I – calculated through ArcGIS 10. Apart from the z-score the Moran´s I tool also computes the Moran's I Index, the expected index, variance, and p-value. A positive Moran´s I Index means that there is spatial clustering, whereas a negative Index expresses dispersion over the area. The calculation of Moran´s I use the following equation (http://help.arcgis.com):

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2},$$

where

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} \quad \text{and} \quad z_I = \frac{I - \mathrm{E}[I]}{\sqrt{\mathrm{V}[I]}}.$$

Z_i stands for the deviation from the mean value of an attribute (in this case asthma rate) for feature *i* (Census Area Unit). The total number of features is *n* and the spatial weight between two features (*i* and *j*) is $w_{i,j}$. S_o is the total of all spatial weights (http://help.arcgis.com).

After the global cluster analysis, indicating the overall pattern the local cluster analysis is performed to find out and visualize where clusters appear. The output is calculated for each area unit individually. Areas with high rates and areas with low rates can be identified, which allows first assumptions of possible reasons that cause these specific patterns. ArcGIS 10 facilitates a local cluster analysis by using the “Getis-Ord GI*” or Hot Spot Analysis. The tool calculates a z-score for each feature. The z-score determines the significance level but also holds the information whether neighbors have high attribute values (with a high z-score) or low values (low z-score) (http://edndoc.esri.com). The GI z-score for this study is created by using the Fixed Distance Band with Euclidean Distance. The Getis-Ord GI* is calculated the following equation (Pfeiffer *et al.,* 2008):

$$Gi(d) = \frac{\sum_{j}^{n} w_{ij}(d)(x_j - \bar{x}_i)}{S_i \sqrt{\frac{w_i(n-1-w_i)}{n-2}}}, \ j \neq i$$

,

where $\bar{x}_i = \frac{1}{n-1} \sum_{j,\ j \neq i}^{n} x_j$, $w_i = \sum_{j,\ j \neq i}^{n} w_{ij}$ and $S_i^2 = \frac{1}{n-1} \sum_{j,\ j \neq i}^{n} (x_j - x_i)^2$,

where n is the number of areas, x_i represents the observed value for the area i and w_{ij} for the symmetric binary spatial weights matrix.

3.2.4.2 Correlation Analysis

Correlation analysis tools are suitable when examining the degree and type of correlation between two or more variables. The relationship of two or more variables can be approached by using bivariate or multivariate spatial correlation analysis to see to what extent one variable determines another one, in this case how the explanatory variables (like environmental or social factors) influence the dependent variable medicated asthma. The equation of the multivariate Moran´s I is given by the following expression (Pfeiffer *et al.*, 2008):

$$I_{kl}^{i} = z_k^i \sum_j w_{ij} z_l^j ,$$

where w stands for the row-standardized spatial weights matrix (which has to be created before the calculation), z_k is the first, z_l the second variable at a location i. The outcome allows the conclusion of whether a positive or negative relationship between the input variables exists and to what intensity. The free software GeoDa offers various spatial analysis tools, including the multivariate LISA (Local Indicator of Spatial Autocorrelation), which is used to calculate the Moran´s I for the dependant variable asthma rate with the above mentioned explanatory variables. The output is displayed as Moran’s scatter plot.

3.2.4.3 Regression Analysis

Regression analysis is applied when the aim is to model, examine and explore the relationship between one dependent variable and at least one explanatory variable (webhelp.esri.com). With the intention of linking and explaining the pattern of the dependent variable (prevalence of asthma) with a set of explanatory variables regression analysis will be used within this study. ArcGIS 10 offers two main tools that can be used in this context to model and analyze spatial relationships for polygons: “Ordinary Least Squares” (OLS) and “Geographically Weighted Regression” (GWR). The Figure 16 presents the equation used for regression analysis. The dependent variable *y* is explained by the explanatory variables *x*. The coefficients stand for the relationship of the dependent and the explanatory variable. In addition, the residuals are computed, which is the part that cannot be explained by the explanatory variables of the regression model (over/under predictions).

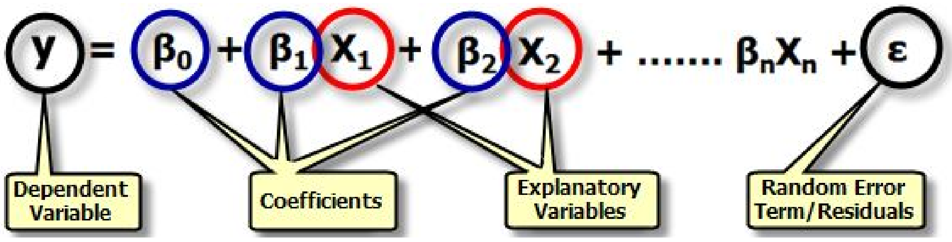


Figure 16 - Equation for Regression Analysis

Source:
http://resources.esri.com/help/9.3/arcgisdesktop/com/gp_toolref/spatial_statistics_toolbox/regression_analysis_basics.htm

The coefficient can either have a negative or a positive sign, depending on the type of relationship of the explanatory variable to the dependent variable (Rosenshein, 2010). The regression tools within ArcGIS are basically meant to build a model. To determine whether a model is good the output report must be interpreted. The multiple and adjusted R^2, which can range from 0 to 1.0 indicate the model performance by declaring how much percent of the pattern of the dependent variable in the study area can be explained through the explanatory variables used in the model (www.arcgis.com).

For each variable a coefficient, probability/robust probability and variance inflation factor (VIF) is computed, which indicate the relationship (positive or negative as well as strength), statistical significance of the explanatory variable and the redundancy among the independent variables.

Whether the probability or robust probability is used depends on the Koenker-test outcome. In case the Koenker-test is statistically significant, the robust probability is used. The VIF should not exceed “7.5”, which would mean that the explanatory variable is redundant. The Koenker-test helps to see whether the variables used in the model have a consistent relationship to the dependent variable – which is medicated asthma. This is effective for both geographical space (which means the explanatory variable is consistent over the study area) as well as the data space (the relationship to the dependent variable is consistent). The null hypothesis states that the model is stationary. “For a 95% confidence level, a p-value (probability) smaller than 0,05 indicates statistically significant heteroscedasticity and/or non-stationarity” (resources.esri.com/help/9.3/ArcGISEngine/java/Gp_ToolRef/spatial_statistics_tools/interpreting_ols_results.htm). As mentioned above, the outcome of the Koenker-test decides whether the analyst has to interpret the robust coefficient standard errors/probabilities for the explanatory variables.

3.2.4.3.1 Exploratory Regression

With the amount of data gathered and used for the analysis, the Exploratory Regression tool, which is part of the Supplementary Statistics Toolbox in ArcGIS, serves as a useful tool to narrow down appropriate variables easily and quickly. The toolbox is not part of the standard ArcGIS version; however it can be downloaded and implemented to the program free of costs from the ArcGIS website (www.arcgis.com). A dependent variable (in this case medicated asthma) is chosen from the *shapefile* followed by the selection of independent variables. The plus of this tool is that it automatically calculates all possible combinations of these variables and gives the most suitable set of explanatory variables. It is also possible to define the minimum and maximum variables used per model. With the standard settings, it automatically searches for matches that fulfill the requirements of a good model used within the Ordinary Least Squares method. For the adjusted R^2 the default value for a passing model is 0,5. All default settings are kept in this case. In this study the Explanatory Regression tool is therefore used first to identify the variables which have the most influence on asthma rate and to search for the best possible model, which is then implemented in the following method – Ordinary Least Squares Regression (OLS).

3.2.4.3.2 Ordinary Least Squares Regression

This type of regression analysis creates only one equation for all explanatory variables. A single coefficient for all variables is computed. OLS assumes that the relationship between the dependent and explanatory variables remain the same for the entire study area. Therefore it is only efficient and suitable when the conditions are expected to be the same over the area (Scott & Janikas, 2010). For this example it is more suitable for the regional scale model when the relationships of variables are more static. For example, due to wind direction the location of major roads and the air pollution can make a difference whether a person is living windward or not. In Ordinary Least Squares Regression it is important that there are no redundant explanatory variables (multicollinearity). This may be the case, for example, partially with New Zealand Deprivation Index and Income or with Elevation and Temperature. Apart from the residual map showing over – and under predictions, OLS also creates coefficient probabilities, standard errors as well as overall model significance (Scott & Jainkas, 2010).

Ordinary Least Squares is a good option to find a model that suits the requirements and a global (for the entire study area) level.

3.2.4.4 Geographically Weighted Regression

After finding a suitable model the settings can be used on Geographically Weighted Regression (GWR) to find the local degree of fitness. Unlike OLS, each geographic location is treated individually (Goovaerts, 2005). Tobler´s law says that close parameters are more similar than parameters that are further apart. So, observations close to one another get a greater weight than observations that are more distant (Charlton & Fotheringham, 2009). Therefore relationships may vary over the study, unlike it is in a global model like OLS (Scott & Janikas, 2010). Geographically Weighted Regression takes variations in relationships over space into account, which is not the case with OLS (Matthews & Yang, 2012). The equation for GWR model is (Matthews & Yang, 2012):

$$\boxed{y_i = \beta_0(u_i, v_i) + \sum_{j=1}^{k} \beta_j(u_i, v_i)x_{ij} + \varepsilon_i}$$

The calculated y_i is the value of the outcome variable at the location i. “$ß_0$ and $ß_1$ represent the local estimated intercept and effect of variable j for location i, respectively” (Matthews & Yang, 2012). With GWR, it is possible to diagnose whether relationships vary across the study area and visually detect “interesting locations” (Matthews & Yang, 2012). The output of GWR is visible as a map (possible as local standard errors, local t-statistics, local goodness-of-fit measures (e.g. R^2) and local leverage measures) (Matthews & Yang, 2012).

4.Results

4.1 General characteristics of asthma distribution

Through disease mapping and the statistics tool within the attribute table in ArcGIS of the various *shapefiles*, general information and clues were gathered. In the subchapters below, the observations are presented, structured by geographical area, beginning with the entire study area New Zealand on a national scale, followed by the regional scale area Auckland.

4.1.1 New Zealand

The prevalence of medicated asthma in New Zealand ranges from 0% to 27,6%. There are two Census Area Units, situated in the North Island, where more than one quarter of the population has medicated asthma. One is located in the center, in the city of Taupo in the middle a hotspot area with increased asthma prevalence. The second one is situated about 120 km south east on the coast. The mean value of medicated asthma is 14,3%. It has to be noted, that this is the proportion of people actually treated with asthma. Whether a person had a serious attack with a hospital admission or a purchase of preventive asthma medication is not differentiated. Also, it may be, that the percentage of people that have asthma, but are not included in this statistic, is higher with lower socio-economic communities and Maoris for example. The map below shows the three main centers of population in a higher scale as well (Auckland, Wellington and Christchurch). Since the CAUs are mostly smaller than the average (due to higher population density), these areas are difficult to grasp on the map for national scale. As this work also focuses on the Auckland area a separate map only for Auckland is created as well (Figure 18).

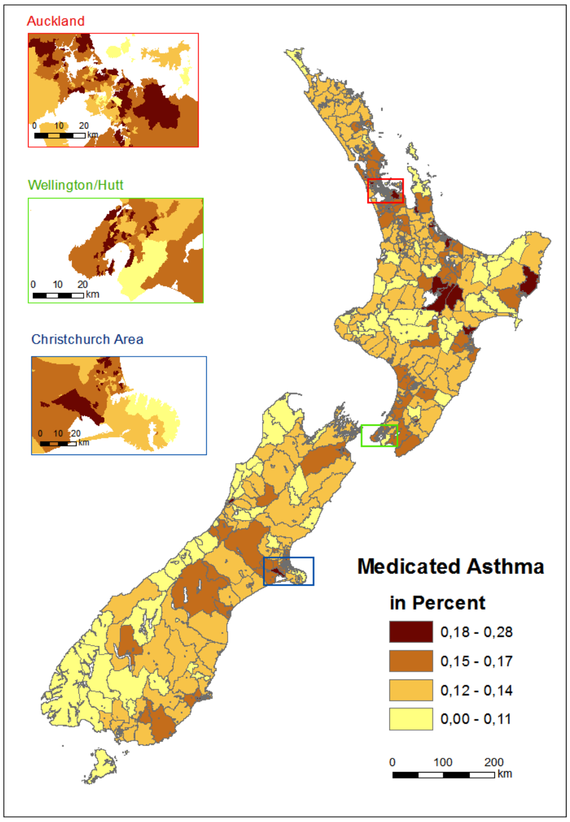


Figure 17 - Asthma prevalence (medicated Asthma) in New Zealand (2009/2010)

4.1.2 Auckland

In the Auckland region 15,3% of the population are medicated because of suffering from asthma. The lowest rates are in the central and southern parts of Auckland (Figure 18), with the lowest Census Area Unit having a proportion of asthma of 7,5%. The highest rate is 21%. The Census Area Units, with the highest asthma are spread throughout the region; however these are situated more on the eastern parts of the study area (both north and south).

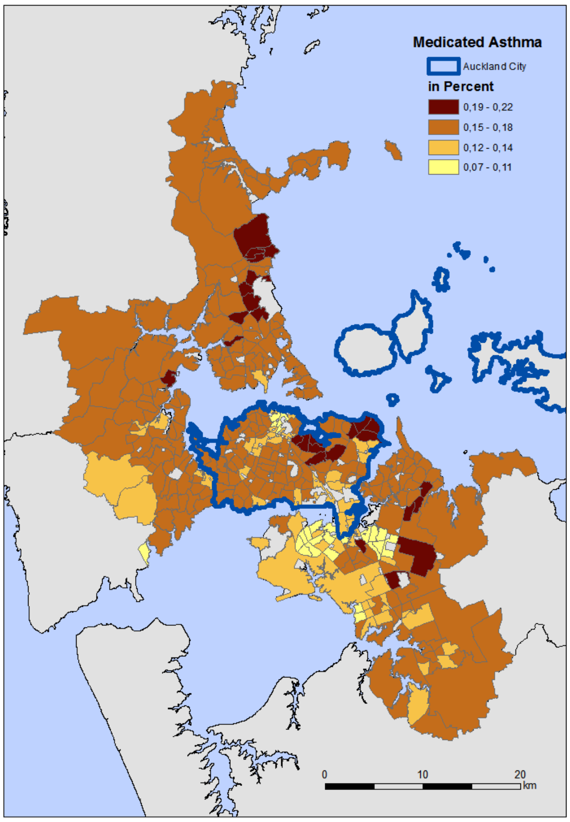


Figure 18 - Mean Asthma prevalence (medicated Asthma) in the Auckland region (2009/2010)

The actual city of Auckland is marked with blue outline. As visible on the map above, the islands are also administrational part of Auckland city. Since they are partially inhabited, they were not included for the representation of asthma prevalence in the Auckland region.

4.2 Cluster Analysis

4.2.1 New Zealand

The Global Moran´s I of the Spatial Statistics Toolbox in ArcGIS 10 gives the results for medicated asthma in New Zealand presented in Figure 19.

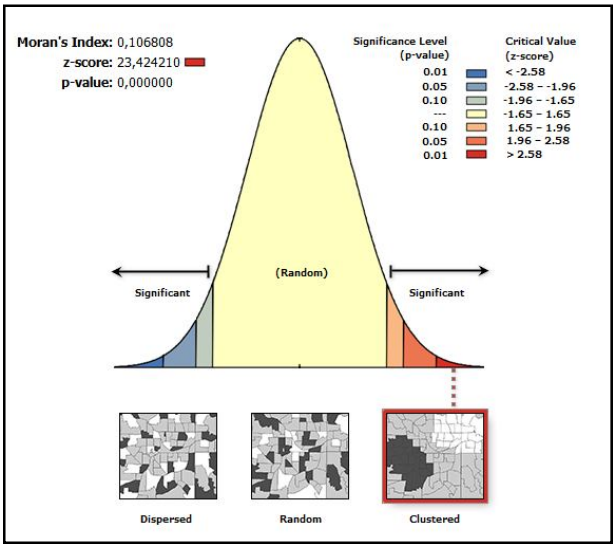


Figure 19 - Spatial Autocorrelation report – New Zealand

With a Z-score of 23,4 and a Moran’s 0,11 the null hypothesis, that the pattern is random, is rejected. The chance that the clustered pattern results out of random chance is less than 1%. The analysis operation shows that spatial clustering appears significantly across New Zealand. The map in Figure 20 (as output from the local cluster analysis) shows where the clusters occur (standard deviation of GI z-score).

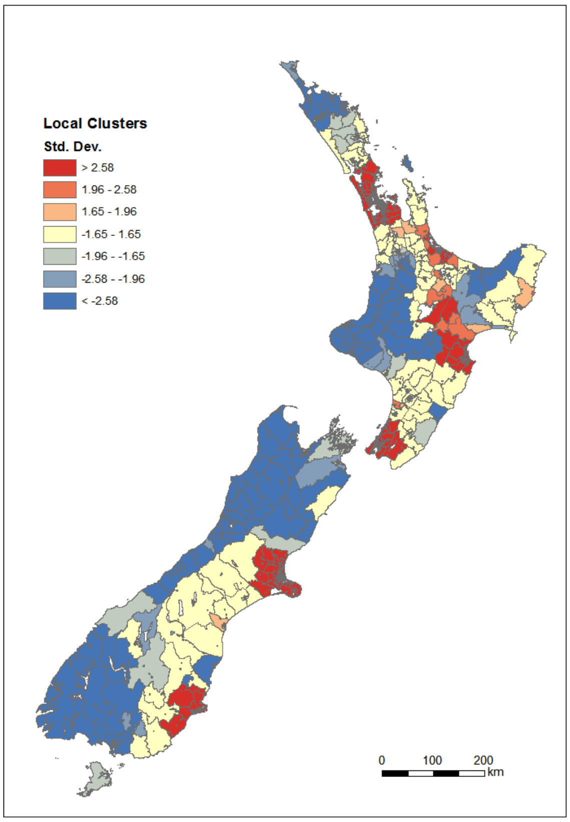


Figure 20 - Local Clusters – Asthma prevalence across New Zealand

The local analysis (Hot-Spot Analysis/Getis Ord GI*) shows that high clusters appear on both main islands all around the Auckland area, the southern tip of the North Island around Wellington and the Hutt area, on a stretch from Tauranga through Rotorua and Taupo to Napier on the North Island and on the South Island around Christchurch and the Otago area as well as further south in the vicinity of the city of Dunedin. Ergo all major urban areas are affected more from asthma – or at least the rate of medicated asthma is significantly higher and clustered compared to other areas of New Zealand. On the other hand low asthma rates are clustered for once in the entire west and north of the South Island, the west of the central part of the North Island, eastern northern part of the central North Island and the most northern part of North Island (Northland) – all of which are more rural areas.

The occurrences of one or more risk factors for asthma in the areas where hot spots are observed are possible or even probable.

4.2.2 Auckland

The Spatial Autocorrelation tool/Moran´s I showed that clustering appears in the Auckland region in terms of asthma rate as well (Figure 21). The Moran´s Index of 0,38 and the z-score of 29,2 both reveal the information that overall in the region of Auckland clusters occur.

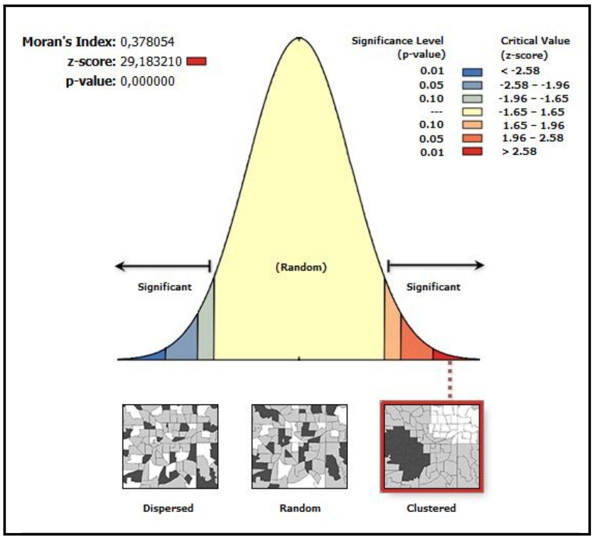


Figure 21 - Spatial Autocorrelation report – Auckland region

The Spatial Autocorrelation report quotes that: “Given the z-score of 29,18; there is less than 1% likelihood that this clustered pattern could be the result of random chance”. Where about these clusters appear is extracted through the local cluster analysis. The Hot-Spot Analysis output map (Figure 22) shows that there are two clusters of high prevalence of medicated asthma. Both are situated on the eastern parts of the region, in the southern and northern areas, bordering to the Pacific Ocean. The one cluster of low asthma prevalence is located on the south west.

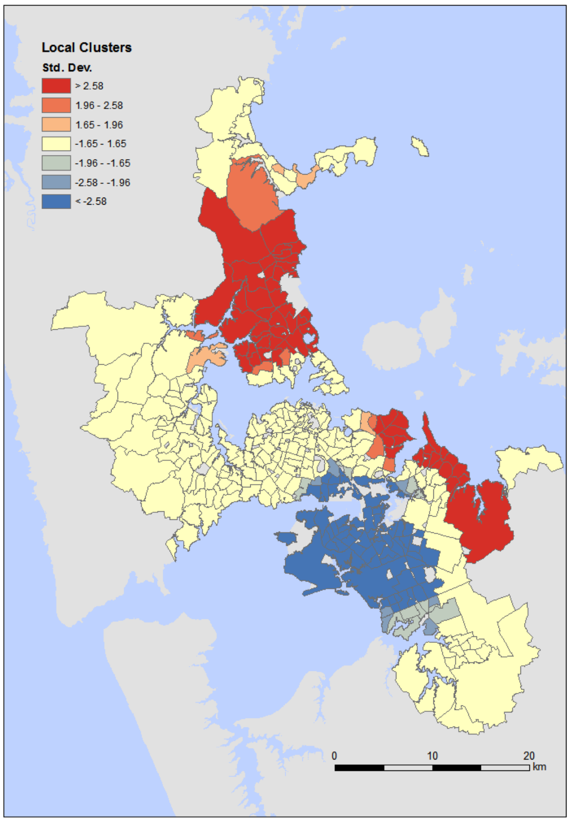


Figure 22 - Local Clusters – Asthma prevalence across the Auckland region

4.3 Relation of Asthma with Independent Variables

After the cluster analysis with the variable asthma prevalence (Tracker), the Multivariate LISA within the software GeoDa and regression analysis through the software ArcGIS have been applied for the different independent variables to examine and illustrate the relation of each individual variable with the rate of medicated asthma. Within this section the variables which showed the highest degree of relation with asthma prevalence are presented.

The approach was made to go from relatively large scale to smaller scale, which means the variables are first tested on the regional scale, which is the Auckland region and then put to the bigger extent – New Zealand.

4.3.1 Regional scale - Auckland

4.3.1.1 Social Characteristics

4.3.1.1.1 Exploratory Regression / Correlation Analysis

As already mentioned Exploratory Regression offers the possibility to simply imply a wide range of variables to see their influence in a short time. The high amount of information extracted from the Census was therefore simply put into the Exploratory Regression tool in thematic differentiation to select the best variable (if any variable was suitable at all). These were then implemented into GeoDa for Multivariate LISA.

At first, all **age groups** (5 year range) were implemented in the tool. It showed that the highest coherence was found within the age groups “45 to 49”. When using two factors together (with percentage of persons aged “65 and over”) this model would explain 27% of the spatial pattern of medicated asthma within the Auckland region. Using only the group “45-49” has an adjusted R^2 of 0,18; while Exploratory Regression computed and adjusted R^2 of 0,09 for the group of "65 and over”. These two variables were thus also analyzed in Multivariate LISA, using GeoDa. The Moran´s I for the age group “45 to 49” is 0,317; for the age group “65 and over” it is smaller with 0,215. Below the scatter plot for “45 to 49” is shown on the left (Figure 23) and “65 and over” (Figure 24) is illustrated on the right.

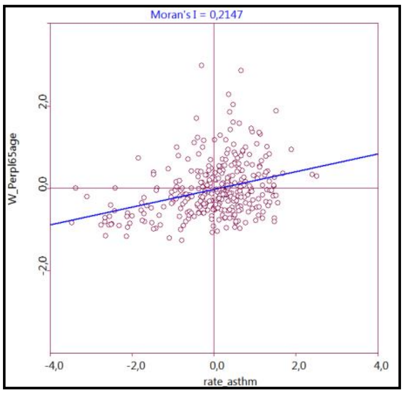


Figure 23 - Correlation between medicated Asthma and age group “45 to 49”

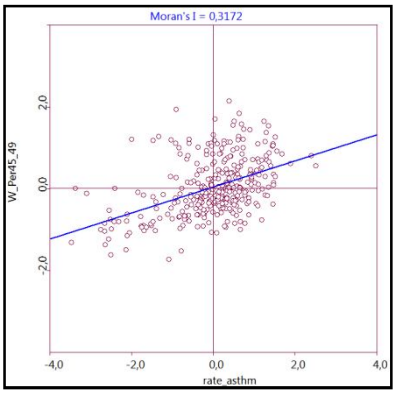


Figure 24 – Correlation between medicated Asthma and age group “65 and over”

Both variables have a positive correlation, which means a higher percentage of these age groups correlate with higher rates of medicated asthma within these Census Area Units.

Looking at **ethnicity** Exploratory Regression reveals that the proportion of Pacific Islanders is the best indicator followed by Europeans and Maori descendants. The pattern can be explained by 41% using the percentage of Pacific Islanders per CAU alone. For Europeans the adjusted R² is 0,28 and for Maori it is 0,23. The same information is revealed when the variables are analyzed with correlation analysis.

The Moran´s I is most elevated for the proportion of Pacific Islanders (-0,493). From left to right the box below shows: Pacific Islanders, Europeans (0,396), Maoris (-0,345).

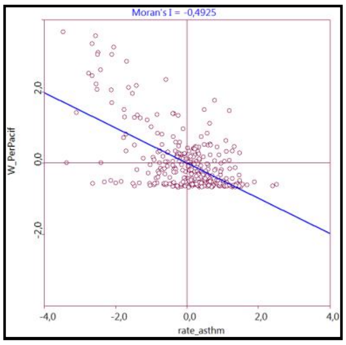


Figure 25 – Correlation between medicated Asthma and proportion Pacific Islanders

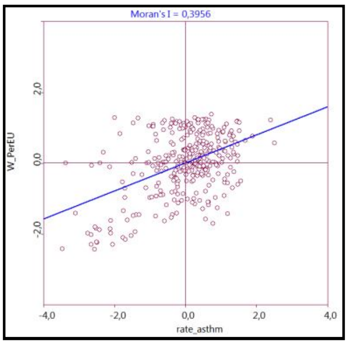


Figure 26 – Correlation between medicated Asthma and proportion Europeans

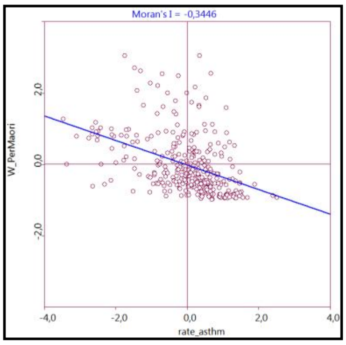


Figure 27 – Correlation between medicated Asthma and proportion Maoris

As the scatter plots show, the relationship for Europeans is positive, meaning higher rates of European descendants per CAU correlate with a higher rate of medicated asthma. On the other side the Moran´s I for both Pacific Islanders and Maori is negative, so higher proportion of these two ethnicity groups go along with a smaller rate of medicated asthma. These results are opposed to the findings of previous studies and statistics where hospital admissions are used. It could be that Maori/Pacific Islander are overrepresented when using the dependent variable of medicated asthma, but underrepresented when using hospitalization, as it is possible that they use less preventive medication due to limited access to health care. However this cannot be proved at this point and is only speculation.

Exploratory Regression with the **number of children** per household shows a quite high adjusted R² for “percentage 2 children” (0,50) and “percentage 6 and more” (0,40). Thus both were implemented into Multivariate LISA in GeoDa. The results confirm a fairly high correlation and also reveal the positive relationship (Moran´s I: 0,483) amongst medicated asthma rate and the percentage of households with 2 children (see Figure 28) and on the other hand a negative relationship (Moran´s I: -0,46) between the proportion of households with 6 or more children and medicated asthma rate.

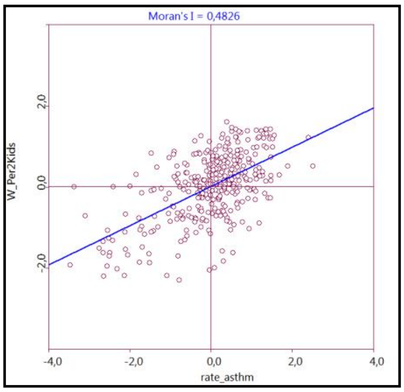


Figure 28 – Correlation between medicated Asthma and proportion of households with 2 children

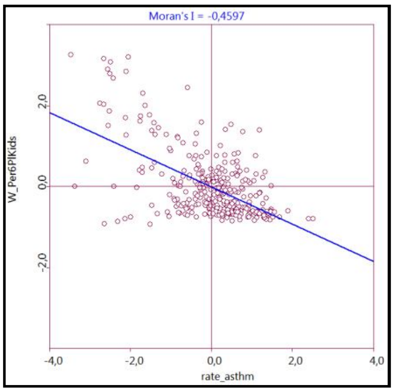


Figure 29 – Correlation between medicated Asthma and proportion of households with 6 or more children

The output report of Exploratory Regression also shows the type of relationship of each variable/classification and enforces the correlation analysis results. A positive relation is found for “no children”, “1 child”, “2 children” and “3 children” but not for “4 children”, “5 children” and “6 or more children”. These findings could be related to the previously mentioned assumption that family members with more siblings have a reduced IgE production because of more frequent viral infections in early childhood (as mentioned in chapter 2.1.3 Common causes for asthma under “Allergens”). On the other hand the assumption that households with a higher number of children (3 and over) and often correlated higher dust levels, raising the probability of asthma cannot be confirmed within this study area. Furthermore it is not to ignore that the dependent variable used in this study – medicated asthma – includes a high proportion of people who use preventive medication or go to the General Practitioner. This also requires a certain standard of living and income, which might not be available to everyone. The following risk factors – personal income and family income - are used to gain further conclusions in this regard.

Personal income is tested next, first within ArGIS using Exploratory Regression, followed by GeoDa´s Multivariate LISA. Exploratory Regression identifies personal income “plus 20,000 NZD” as the most appropriate to use. The adjusted R² using only this variable lies at 0,43. As seen in the scatter box below, the positive relationship with a Moran´s I of 0,3959 extracted from Multivariate LISA Census Area Units with a higher proportion of people with an income of at least 20,000 NZD correlate with higher medicated asthma. This would confirm the assumption that when taking the variable “medicated asthma” in particular show a higher prevalence within more wealthy populations rather when using hospitalization data for instance.

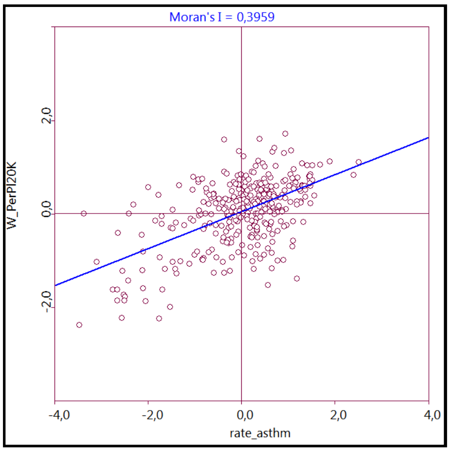


Figure 30 – Correlation between medicated Asthma and proportion of people with income of more than 20,000 NZD

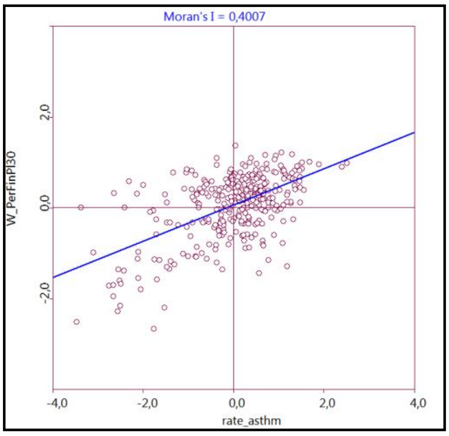


Figure 31 – Correlation between medicated Asthma and households with family income with more than 30,000 NZD

The variable **family income** is also tested since it includes children also and not only the working population as does the previously used variable personal income. The outcome reveals a higher rate of medicated asthma within higher social classes as well. The highest adjusted R² is reached when using percent of households with family income 30,000 NZD and higher (adjusted R²: 0,46). The Moran´s I for this variable is 0,400.

The analysis on **employment status** shows that the percentage of unemployment and the percentage of part-time employment have the highest adjusted R². For unemployment Exploratory Regression calculates 0,29 and for part-time employment it is 0,28.

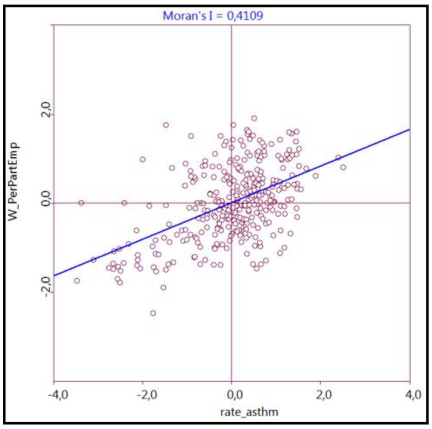


Figure 32 – Correlation between medicated asthma and percentage of population being part-time employed

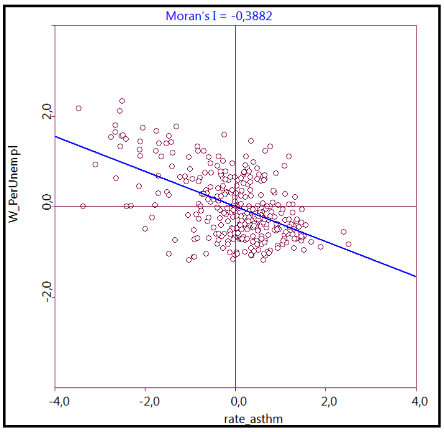


Figure 33 - Correlation between medicated Asthma and percentage of unemployed population

With Multivariate LISA it is revealed that the correlation, using this analysis is higher for part-time employment (Morans´s I of 0,411). The relationship is positive. A higher proportion of part-time employed working force is correlating with higher rate of medicated asthma. The relationship with unemployed population is negative (-0,388), so higher rate of unemployed population per CAU is observed to correlate with less prevalence of medicated asthma. Again this might be due to financial resources, being able to afford medication and visits at the General Practitioner. Of course this is only one possible explanation and a further investigation on individuals in further studies could provide understanding.

Analyzing the **means of travelling to work** results in an adjusted R² of 0,20 looking at the percentage travelling by car (all combined: private, company or as passenger). The next highest adjusted R² is observed for proportion of the working population that is not using motorized means of going to work (adjusted R² 0,11). The left scatter plot (Figure 34) shows the results from Multivariate LISA correlation analysis for the percentage that uses a car to go to work, while the right (Figure 35) represents the population using a bicycle or walking.

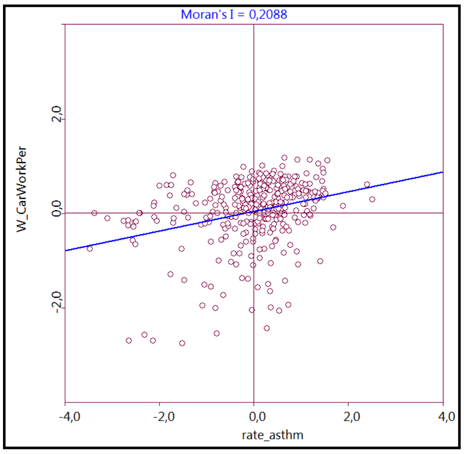


Figure 34 – Correlation between medicated Asthma and percentage of population going to work by car

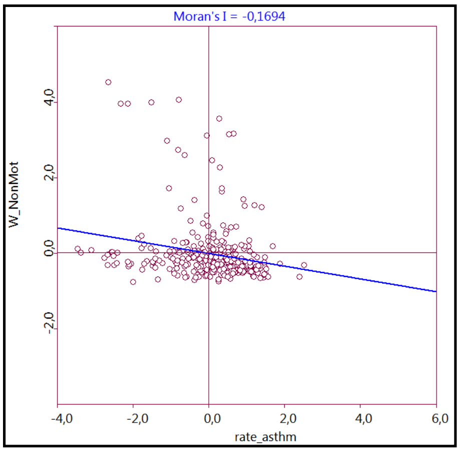


Figure 35 – Correlation between medicated Asthma and percentage of population going to work by bicycle/foot

The relationship for the percentage of population using a car and rate of mediated asthma is positive (Moran´s I of 0,209). Opposed is a negative relationship between non-motorized means of travelling and prevalence of medicated asthma (Moran´s I: -0,169). The low adjusted R^2 for non-motorized type of travelling to work makes this variable rather secondary for the further regression analysis (OLS and GWR). The percentage of working population travelling by car to work is therefore considered as most important category within means of travelling to work for the continuative analysis.

Next the **level of qualification** is examined. With the Exploratory Regression tool, the highest adjusted R^2 within the qualification variables is percent of population holding a diploma degree (0,37) followed by percentage with no qualification (0,22). The Moran´s I from the correlation analysis is 0,436 for percentage of the population holding a diploma and -0,356 for the proportion without a qualification.

Thus these results, just like the observations done within income, number of children and even the ethnicity (where Maoris show the highest correlation with a negative relationship to medicated asthma), reveal that a high rate of medicated asthma correlates inversely with the proportion of lower social classes. The highest coherence for the population with a diploma shows that the highest educated population (doctorate as well as post-graduate education) has less significant relation than the population with diploma only. The initial assumption would have been that asthma prevalence correlates with less qualified population, due to worse living conditions and less access to health care.

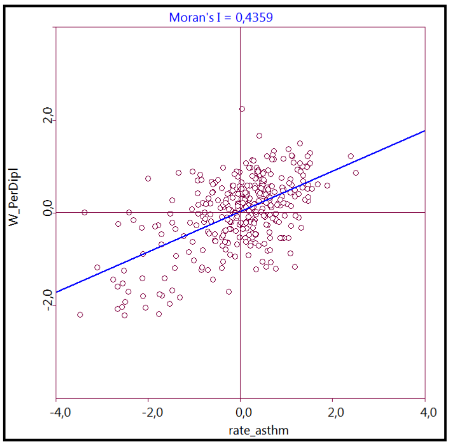


Figure 36 – Correlation of medicated Asthma with percentage of population with Diploma

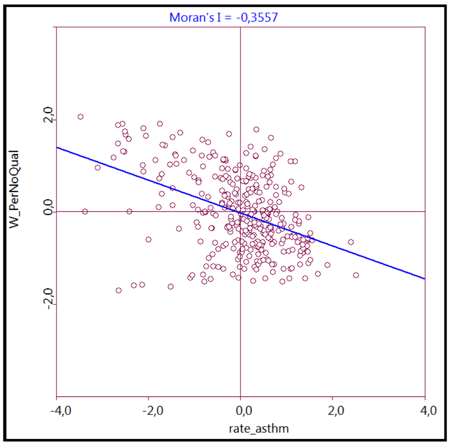


Figure 37 – Correlation between medicated Asthma and percentage of population without school qualification

Next, within the social characteristics variables the **New Zealand Deprivation Index** is subject of the analysis. The adjusted R² hereby calculated is 0,36. Like in the examples before Multivariate LISA is applied to identify the correlation through the Moran´s I and the type of relationship. With a Moran´s I of -0,431 the correlation is fairly strong and negative. As the deprivation ranges from 1 to 10, with 10 being the maximum in terms of deprivation, the analysis confirms the already observed pattern, where higher social status correlates with higher rates of medicates asthma. It can be assumed that these findings result out of the reduced access of lower social economy classes to health care service. As medicated asthma does not only include emergency cases, such as hospital admissions, but also individuals who purchase and use inhalers for example the rate for asthma prevalence might be shifted, so that there is a higher dark figure within lower socio-economic groups.

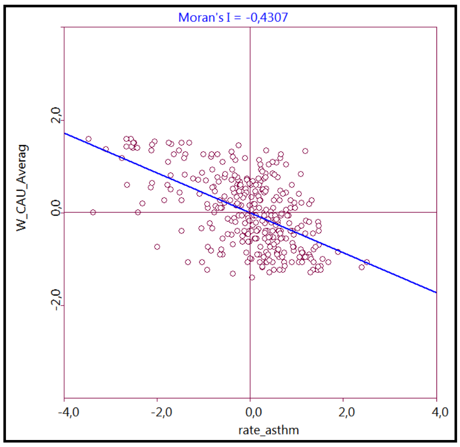


Figure 38 – Correlation between medicated Asthma and NZ Deprivation Index

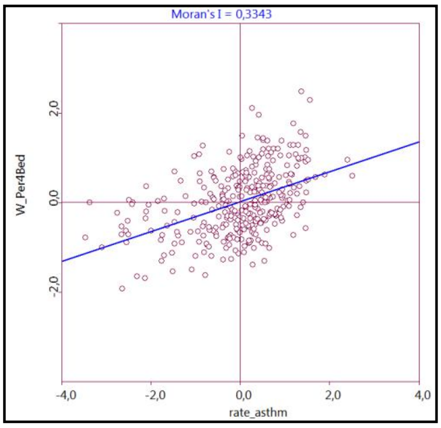


Figure 39 – Correlation between medicated Asthma and percentage of households with 4 bedrooms

For housing characteristics, at first the **number of bedrooms per household** is the focus of the analysis. As extracted from Exploratory Regression the highest adjusted R² is observed for Census Area Units with 4 bedrooms (0,26). As illustrated in the scatter plot (Figure 39) the Moran´s I is 0,334 and the relationship is positive. Thus it shows that in this context when it comes to bedrooms a higher number of bedrooms does correlate with higher asthma prevalence, as mentioned in the theory part of this work (in context with higher dust levels). This also shows in the second highest adjusted R² which is for household with 4 or more bedrooms (fields were created in the attribute table which summarized the percentage of more than 2 bedrooms, more than 3 etc.). The adjusted R² here is 0,22; which is still long before the third most highest adjusted R² of 0,16 for proportion of 3 and more bedrooms.

The **type of heating** as well as the **domestic emissions**, showed very little correlation. The Exploratory Regression computed and adjusted R² of 0,06 for percentage of negative heating per CAU and 0,03 for the emissions (PM/g) per hectare. Multivariate LISA confirms this low connection between the independent variables with the rate of medicates asthma. The Moran´s I for domestic emissions, coming from coal and wood, is 0,066; for the percentage of households using heating types that are considered to harm the respiratory tract the Moran´s I is 0,188.

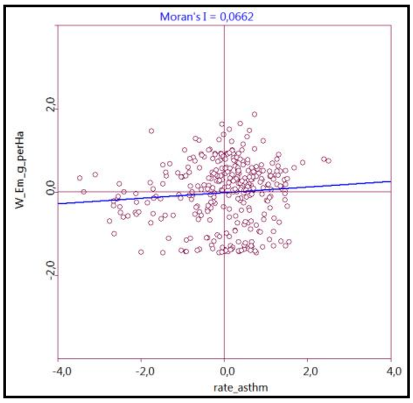


Figure 40 – Correlation between medicated Asthma and domestic heating emissions (PM/g)

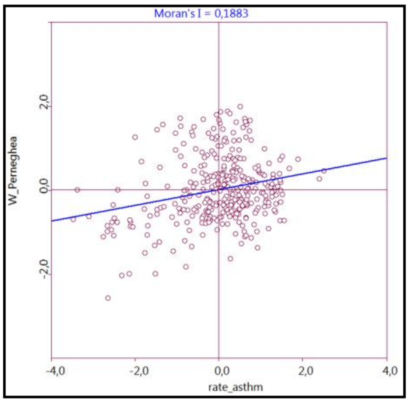


Figure 41 – Correlation between medicated Asthma and percentage of households using negative heating types

Table 3 contains a summary of the so far realized analysis to review the selected categories of the variables used for further analysis along with their adjusted R² (only using this individual analysis) and Moran´s I.

Table 3 - Summary of Regression and Correlation analysis for social variables – Auckland region

Variable	**Appropriate Category**	**Adjusted R²**	**Moran´s I**
Age	**45-49**	**0,18**	**0,3172**
	65 and over	**0,09**	**0,2147**
Ethnicity	**Proportion of Pacific Islanders**	**0,41**	**-0,4925**
Number of children	**2 children**	**0,50**	**0,4826**
	6 and over	**0,40**	**-0,4597**
Personal Income	**20,000 NZD and over**	**0,43**	**0,3959**
Family Income	**30,000 NZD and over**	**0,46**	**0,4007**
Employment Status	**Part-time employed**	**0,28**	**0,4109**
	Unemployed	**0,29**	**0,3382**
Travel means to work	**Car**	**0,20**	**0,2088**
	Non-motorized	**0,11**	**-0,1694**
Qualification	**Diploma**	**0,37**	**0,4359**
	No Qualification	**0,22**	**-0,3557**
NZ Dep		**0,36**	**-0,4307**
Number of Bedrooms	**4 Bedrooms**	**0,3343**	**0,3343**
Percentage with negative heating		**0,06**	**0,1883**
Domestic emissions		**0,03**	**0,0662**

Running the Exploratory Regression with all the 17 variables mentioned in the table is the first test to see to what extent these chosen social characteristics are suitable to build a model on risk factors for medicated asthma. The highest number of variables to combine is 5, which is respecting the default setting of the Ordinary Least Squares analysis.

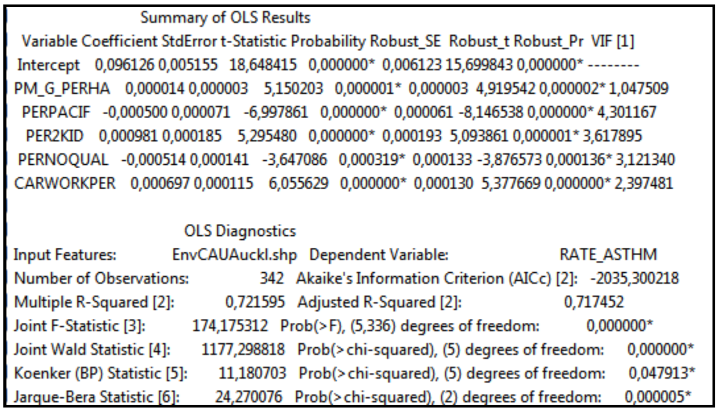
The highest adjusted R² is computed when using any of the 3 combinations:

- Domestic heating emissions, percentage Pacific Islanders, percentage 2 children, percentage no qualification, percentage of population going to work by car;
- Domestic heating emissions, percentage Pacific Islanders, percentage of population of at least 65 years old, percentage of households with 4 bedrooms, percentage of population going to work by car;
- Domestic heating emissions, percentage Pacific Islanders, percentage 2 children, percentage income at least 30,000 NZD, percentage of population going to work by car.

All three combinations of attributes result in an adjusted R² of 0,72. This fulfills the default requirements of a passing model (where an adjusted R² should be at least 0,50) when using the standard requirements for Ordinary Least Squares models. This model also is appropriate when it comes to redundancy in variables. All of the models have a VIF of less than 7,5 which is the critical value. The first one of the above listed combinations has a value of 4,30; the second one has 1,71 and the third one 4,03. 86% of all the models that were run by the Exploratory Regression tool pass this requirement. For the Jarque-Bera p-value test (for normally distributed residuals) only 12% of the models are qualifying for a good model. None of the models that the Exploratory Regression tool built fulfilled the standard requirements of the Moran´s I p-value (testing for spatial autocorrelation), which means that the residuals are not random. Thus the conclusion at this point of the analysis: at least one key variable is still missing to determine a good model for risk of medicated asthma.

4.3.1.1.2 Ordinary Least Squares

In the next step Ordinary Least Squares is applied with the best computed model (domestic heating emissions, percentage Pacific Islanders, percentage 2 children, percentage no qualification, percentage of population going to work by car) from Exploratory Regression to receive a visual output, which can lead to conclusions about missing key variables. The box in Figure 42 shows the results of the model executed in ArcGIS.



```
                    Summary of OLS Results
 Variable Coefficient StdError t-Statistic Probability Robust_SE  Robust_t Robust_Pr  VIF [1]
 Intercept    0,096126 0,005155   18,648415   0,000000*  0,006123 15,699843 0,000000* --------
PM_G_PERHA    0,000014 0,000003    5,150203   0,000001*  0,000003  4,919542 0,000002* 1,047509
 PERPACIF   -0,000500 0,000071   -6,997861   0,000000*  0,000061 -8,146538 0,000000* 4,301167
  PER2KID    0,000981 0,000185    5,295480   0,000000*  0,000193  5,093861 0,000001* 3,617895
 PERNOQUAL   -0,000514 0,000141   -3,647086   0,000319*  0,000133 -3,876573 0,000136* 3,121340
CARWORKPER    0,000697 0,000115    6,055629   0,000000*  0,000130  5,377669 0,000000* 2,397481


                         OLS Diagnostics
Input Features:           EnvCAUAuckl.shp   Dependent Variable:                  RATE_ASTHM
Number of Observations:              342   Akaike's Information Criterion (AICc) [2]:   -2035,300218
Multiple R-Squared [2]:          0,721595   Adjusted R-Squared [2]:                  0,717452
Joint F-Statistic [3]:        174,175312   Prob(>F), (5,336) degrees of freedom:        0,000000*
Joint Wald Statistic [4]:       1177,298818   Prob(>chi-squared), (5) degrees of freedom:     0,000000*
Koenker (BP) Statistic [5]:       11,180703   Prob(>chi-squared), (5) degrees of freedom:     0,047913*
Jarque-Bera Statistic [6]:       24,270076   Prob(>chi-squared), (2) degrees of freedom:     0,000005*
```

Figure 42 – Summary of OLS Results – Social Model - Auckland region

The social characteristics alone already have a high adjusted R² of 0,72 and also the VIF values, as well as the coefficient p-value fulfill the requirements. The Koenker-test tells that the heteroscedasticity is not significant, ergo stationarity applies. Therefore the Joint F-Statistic can be taken to evaluate the model statistical significance. Up to this point the filtered explanatory variables are suitable to model the risk factors of asthma. But the major concern is the clustering of residuals. The results of the Jarque-Beta, shows that the residuals or not normally distributed. With the p-value being smaller than 0,05 (when using a 95% confidence level) the test reveals that the residuals are not randomly distributed. It could either indicate that the relationships between the independent variables and the dependent variable medicated asthma are not linear or it means that at least one key variable is not included in the model. This is not surprising since up to this point environmental variables – which are expected to have an effect on asthma – were not included in the analysis. OLS now comes to hand to look at the pattern of the residuals, which are illustrated in the map (Figure 43). The map for standard residuals shows that larger Census Area Units which lie more in the outskirts of the Auckland region are rather categorized with a negative standard deviation, while the central areas show frequent positive standard deviations as well. To analyze the pattern more, again a Spatial Autocorrelation (Moran I) followed by a local analysis (Hot Spot Analysis) are utilized to gain further clarification.

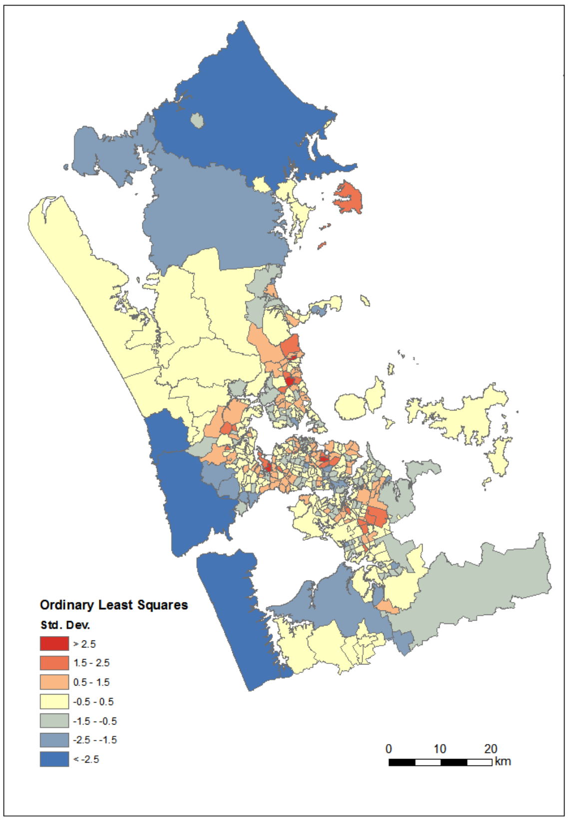


Figure 43 – Ordinary Least Squares Model – Social Characteristics – Auckland region

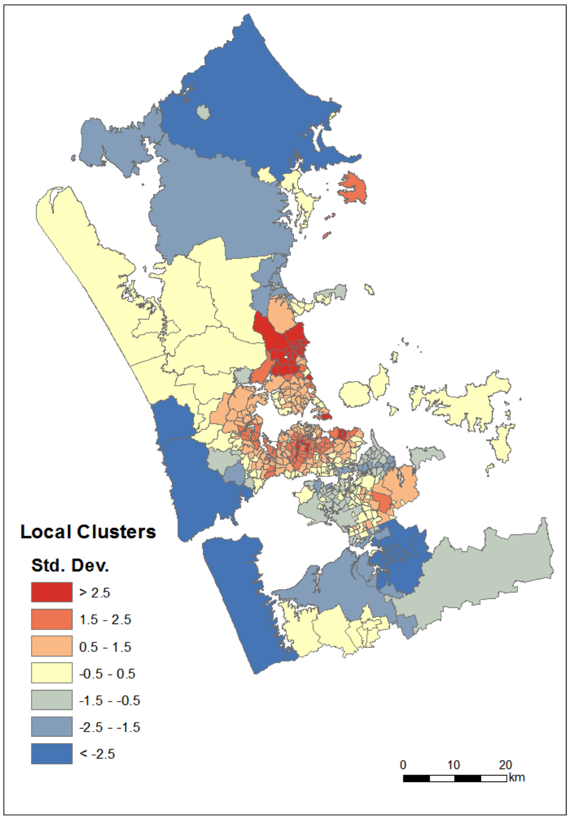


Figure 44 – Local Clusters of Standard Residuals (OLS) – Social Characteristics – Auckland region

As was already indicated through Exploratory Regression and OLS, clustering appears over the study area. The z-score of 7,63 but also Moran´s I 0,096 confirm the previous observation. Getis Ord GI* Hot Spot Analysis delivers the visual output to see where the clustering is found. The first impression is confirmed by the Cluster Analysis. Over predictions are found more in the larger CAUs, which are located in the outskirts of the Auckland region, while the city of Auckland itself is more dominated by under predictions. The closer vicinity of Auckland city is mixed with both under- and over predictions.

4.3.1.1.3 Geographically Weighted Regression

The Geographically Weighted Regression considers that the relationship of explanatory variable and dependent variable may vary throughout the study area. The adjusted R² therefore is slightly higher (0,73) than for the global analysis of Ordinary Least Squares. So the five variables selected (domestic heating emissions, percentage Pacific Islanders, percentage of population of at least 65 years old, percentage of households with 4 bedrooms, percentage of population going to work by car) can explain 73% of the pattern of medicated asthma in the Auckland region. The map in Figure 45 shows that over predictions mostly appear throughout the city centre but also in the most suburban areas, whereas under predictions fall in particular for the city area and the close vicinity of Auckland city.

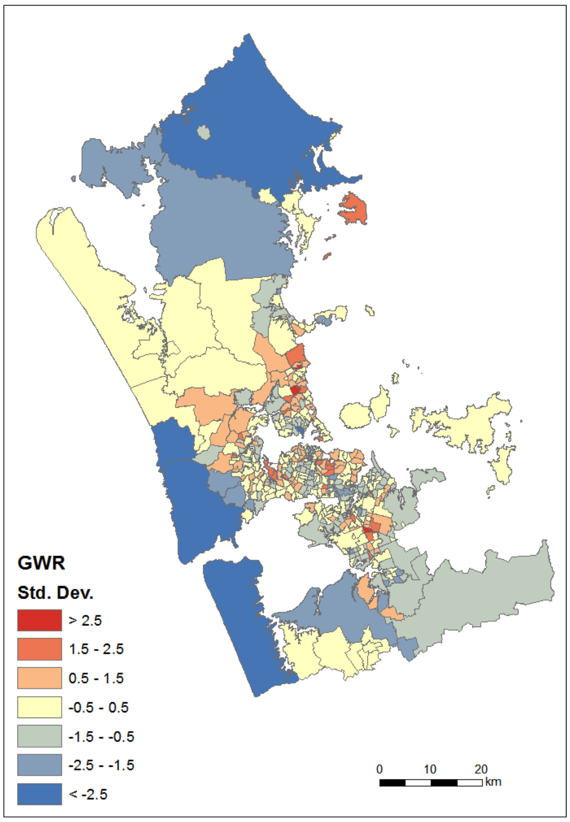


Figure 45 – Geographically Weighted Regression – Social Characteristics – Auckland region

4.3.1.2 Mapping of spatial characteristics

Regression/correlation analysis was tested on all available variables using Exploratory Regression, since all variables had a very small adjusted R^2 (the maximum was achieved for rainfall with 0,05 adjusted R^2) the findings are not relevant to build a good model. However this chapter presents mapping of spatial attributes, which are not eligible for a regression analysis to see whether these factors are influencing the spatial distribution of medicated asthma prevalence in the Auckland region.

4.3.1.2.1 Road traffic

For the Auckland region the results of buffer zones around all highways (major highways and principal highways) are shown in Figure 46:

With one exception, all of the Census Area Units with the highest asthma rate (Tracker) are situated either within a buffer zone of 1 km or at east of them. Since there are predominantly winds from the west (McClure, 2010) in Auckland, high traffic volume seems to be partially responsible for high asthma rates in Auckland. At the same time, it has to be noted that the 13 Area Units with the lowest asthma rates (between 7 and 10%) are also located in close proximity of major and principal Highways (see Figure 47). Thus road traffic alone cannot be the only key aspect for asthma, even though a relation seems probable.

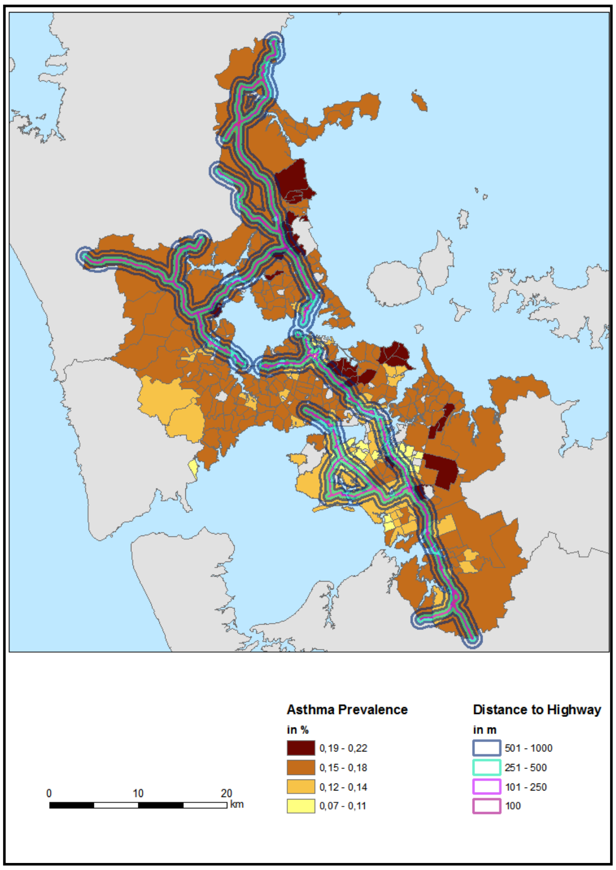


Figure 46 - Buffer zones for Highways within the Auckland area in the context of asthma prevalence

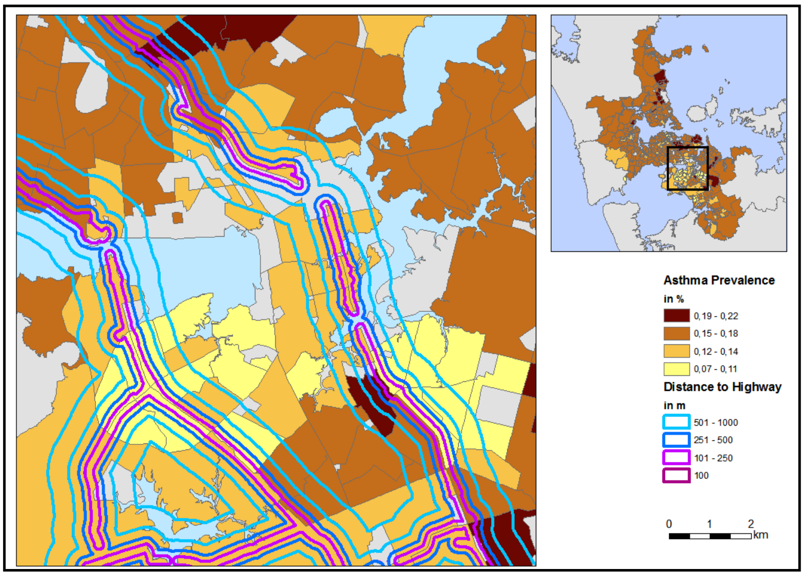


Figure 47 - Low asthma prevalence within/close to buffer zones of Highways

4.3.1.2.2 Landfills

In the urban region of Auckland there are 4 landfills (named A,B,C and D in Figure 48). Landfills A and B are located in an area with 15 to 18% and D is in an area where the rate of asthma is even between 19 to 22%. Keeping in mind the prevailing wind direction from the west, it is also noticeable that there are several Census Area Units with the highest asthma prevalence in wind direction, which are affected by landfill B. A similar situation can be found in the northern part of the Auckland region, with one landfill (named E in Figure 48), which is not part of the actual study area, but situated approximately 500 meter from another area, which is the highest category of medicated asthma prevalence (19-22%). All landfills except for one are within Census Area Units with high to very high asthma prevalence (15 to 22%). Landfill C however is the only landfill that is situated in an area with less than 15% medicated asthma rate. This landfill is located in a CAU where the medicated asthma prevalence is between 12 and 14%.

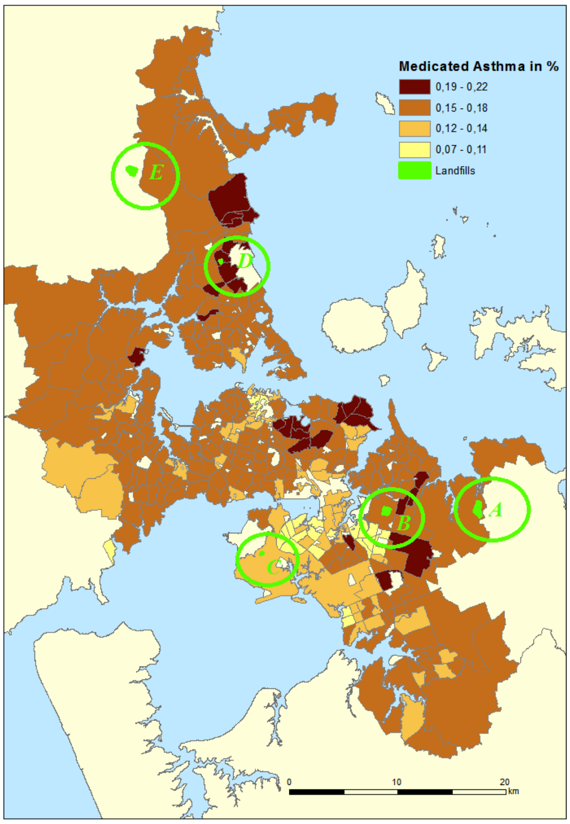


Figure 48 - Coherence of medicated asthma prevalence and location of landfills

4.3.2 National scale - New Zealand

4.3.2.1 Social Characteristics

4.3.2.1.1 Exploratory Regression/Correlation Analysis

With the same approach as used for the Auckland region, New Zealand as a whole is now the focus for the social characteristics. Again, all variables are tested first, to eliminate the attributes that are dispensable. Under each factor there is also a remark about similarity/disparity compared to the Auckland region analysis. A summary of all social characteristics with their adjusted R² (regression analysis) and Moran´s I from correlation analysis is arranged after the last individual variable.

First of all, some CAUs had to be excluded from the analysis process, because they showed no population for the Census data and therefore were not usable. These areas are shaded in grey in the upcoming maps.

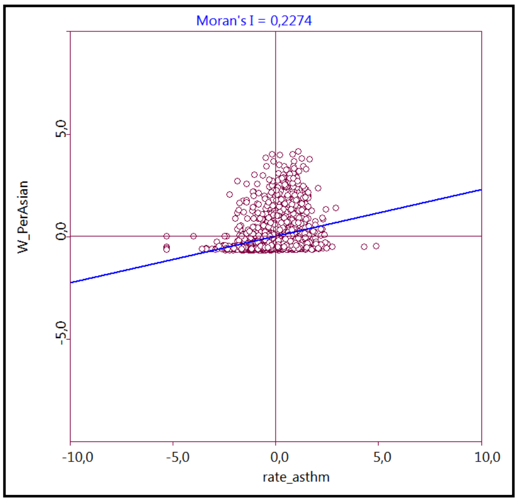


Figure 49 – Correlation between medicated Asthma and proportion of Asians

Ethnicity only shows a weak relationship when applied for the entire study area of New Zealand. The highest adjusted R² (positive relationship) was found for Asians (0,06) followed by percentage of Maoris (0,05) with a negative relationship. So the highest adjusted R² found is much less than for the Auckland region analysis. Looking at the output file for the Auckland region reaffirms that the relationship types between medicated asthma and proportion of Asians is positive as well, just like the relationship to the Maori population is negative in both study areas. So it is only the degree to which the pattern can be described which differentiates, the type of relationship remains the same in both scenarios. The correlation analysis confirms the positive correlation between the proportion of Asians per Census Area Unit and the rate of medicated asthma (Moran´s I: 0,227). However, the Moran´s I for the best suitable characteristic amongst the variable ethnicity for the Auckland region, which is Pacific Islanders (-0,493), is more than twice as high as the Moran´s I for New Zealand (0,227). The Moran´s I can range between -1 and 1. The closer it is to either -1 or 1, the higher the correlation between the examined dependent variable and independent variable.

Applying **age group** into the regression analysis, reveals that the highest adjusted R² is only 0,02 when using only one characteristic and 0,07 when using 2 characteristics: “35-39” and “over 65 years” age groups. Thus this variable cannot contribute to a suitable model. As none of the age groups showed a relevant relationship, the correlation analysis was not applied for the factor age group.

The **number of children** at least can explain 10% of the pattern of medicated asthma prevalence when using the “2 children” characteristic (positive relationship) and 0,09 for “6 and more children” (negative relationship). So it matches the results from the regional scale analysis, where also these two characteristics showed the highest adjusted R², even though it was with 0,50 for “2 children” and 0,40 for “6 and more children” considerably higher. The same applies to the Moran´s I, which is 0,166 for “2 children” for the national analysis (scatter plot below on the left), compared to 0,483 for Auckland; and -0,227 for “6 and more children” (scatter plot on the right) and -0,46 for the correlation analysis for New Zealand.

When using 2 variables combined the adjusted R² is 0,18 for “no children” (positive relationship) and “2 children”.

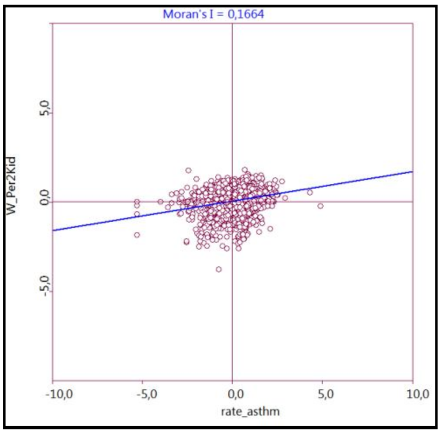


Figure 50 – Correlation between medicated Asthma and proportion of households with 2 children

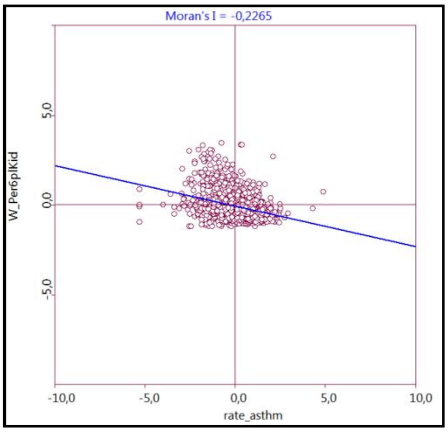


Figure 51 – Correlation between medicated Asthma and proportion of households with at least 6 children

The observation for the variable “number of children” complies with, what has already been noted for the variable “ethnicity”. The relationship types are the same for both study areas, but the degree of explanation of the medicated asthma pattern through the variable cannot compare, as the pattern of the Auckland region can be explained to a much higher degree than for the entire country.

The **personal income** shows the following results: percentage of population having a personal income of “30,000 NZD and more” predicts the pattern the best with an adjusted R² of 0,13; followed by percentage of working population with in income of “more than 50,000 NZD” (adjusted R²: 0,12). Both have positive relationships.

The Moran´s I for percentage with a personal income of “at least 30,000 NZD” calculated through correlation analysis is 0,212 illustrated on the left scatter plot below (Figure 52); for the proportion with an income “50,000 NZD and more” it is 0,2351 (Figure 53).

The percentage of population with a personal income of at least 30,000 NZD is not amongst the selected characteristics for the model built for Auckland, but looking at the Exploratory Regression output again, reveals that with an adjusted R² of 0,41 it takes place three and coincides having a positive relationship to medicated asthma rates.

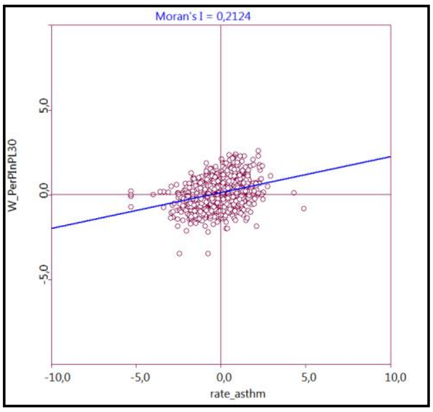


Figure 53 – Correlation between medicated Asthma and percentage of population with Personal Income at least 30,000 NZD

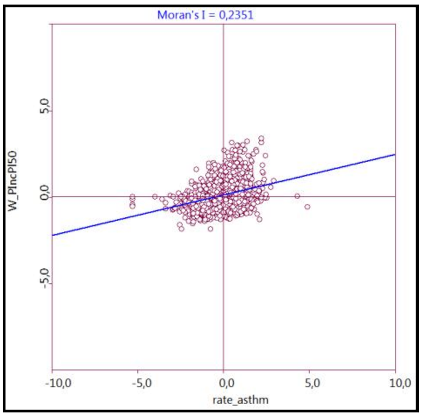


Figure 52 – Correlation between medicated Asthma and percentage of population with Personal Income at least 50,000 NZD

Slightly higher is the adjusted R² that has been calculated for **family income**. Both family income of “70,000 NZD and more” and “50,000 NZD and more” have 0,14 and positive relationships. The percentage of families with an income of “70,000 NZD and more” combined with proportion of families with an income of “20,000 to 30,000 NZD” (negative relationship) has 0,18 adjusted R². As the previous results from Multivariate LISA, the Moran´s I lie in their 0,20´s with 0,256 for “70,000 NZD and more” (Figure 54) and 0,226 for proportion of an income with “50,000 NZD and more” (Figure 55).

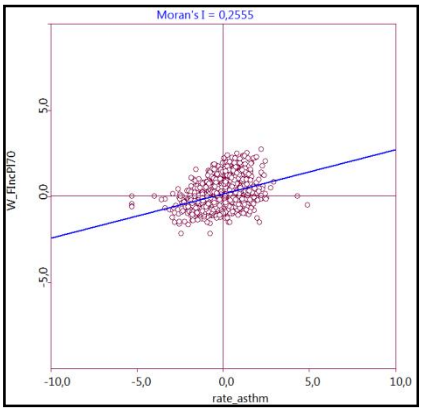


Figure 54 – Correlation between medicated Asthma and proportion of households with at least 70,000 NZD

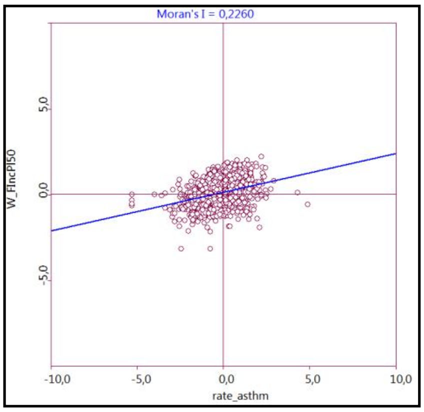


Figure 55 - Correlation between medicated Asthma and proportion of households with at least 50,000 NZD

The Exploratory Regression output shows that the two most suitable characteristics of the national scale analysis “70,000 NZD and over” and “50,000 NZD and over” also have the 2nd and 3rd highest adjusted R² in the Auckland region analysis (0,43 for income of at least 50,000 NZD and 0,38 for family income of at least 70,000). Also all relationships are positive in both scenarios.

Using **employment status** as rate per CAU for exploratory regression shows that this variable is not eligible for the prediction of medicated asthma for New Zealand. Only 0,02 for percentage part-time employed is caluclated as the highest adjusted R². With the low adjusted R² the correlation analysis was not applied for status of employment.

The Exploratory Regression shows, that within the variable **means of travelling** to work, the percentage of population driving to work by car (either as passenger or driver, including private and company vehicles) explains the medicated asthma pattern the best. The adjusted R², that was calculated is 0,15. For population going by bus it is 0,06. Combining these two results in an adjusted R² of 0,23. Both are labeled as significant. With GeoDa the output of Multivariate LISA as scatter plot shows the positive relationship and a Moran´s I of 0,286 for proportion driving by car and 0,243 for proportion going to work by bus, which is still fairly high, given the adjusted R² of only 0,06.

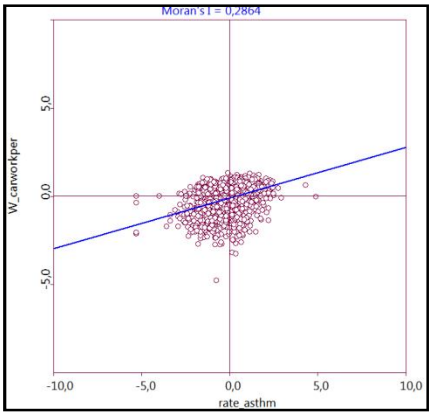


Figure 56 – Correlation between medicated Asthma and percentage of population going to work by car

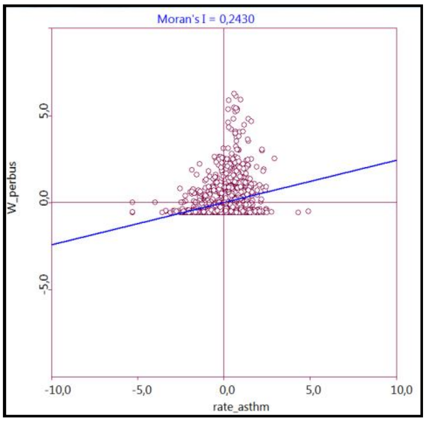


Figure 57 - Correlation between medicated Asthma and percentage of population going to work by bus

For Auckland it was a positive relationship for car drivers with an adjusted R² of 0,20 and a Moran´s I of 0,209, which had the best eligibility. Sure enough the adjusted R² that were found for the Auckland region is higher, but the Moran´s I from the correlation analysis shows a higher fit in correlation between percentage driving to work by car and medicated asthma for New Zealand compared to Auckland. Also, this variable is the most suitable factor to explain the pattern within the social characteristics variables.

Within the variable **education** the highest adjusted R² was found for percentage of population holding a postsecondary degree: 0,13 (positive relationship), followed by 0,11 for the percentage with a bachelor degree (positive relationship). Both are implemented in GeoDa with the following results: the Moran´s I for percentage of population with a postsecondary degree is 0,261 (see scatter plot below on the left); for population with a bachelor degree it is even 0,2807 (scatter plot on the right), which makes it the highest Moran´s I of the so far examined variables within the social characteristics of the country wide correlation analysis.

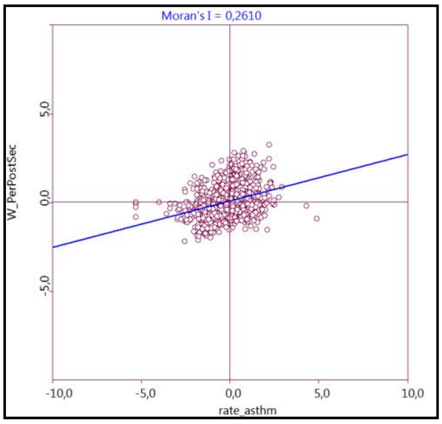


Figure 58 - Correlation between medicated Asthma and percentage of population with postsecondary Degree

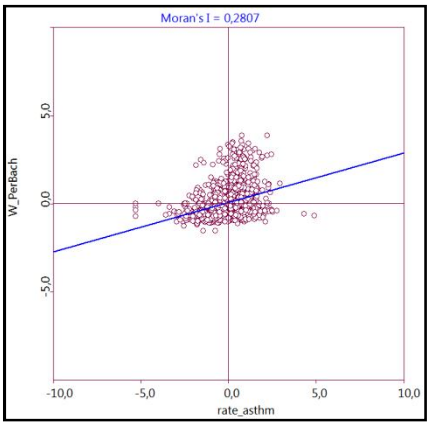


Figure 59 - Correlation between medicated Asthma and percentage of population with postsecondary Degree

The two categories that have the highest adjusted R² for the national regression analysis do not show up within the top categories for the Auckland analysis. However, the proportion of people with a bachelor degree has still a higher adjusted R² for the Auckland analysis (0,18) than for the New Zealand analysis (0,11). For both study areas the relation between Bachelor Degree holders and medicated asthma is positive.

The **New Zealand Deprivation Index** only explains 6% of the pattern of medicated asthma across New Zealand. This is 30% less than for the Auckland region analysis, where the adjusted R² is 0,36. The Moran´s I is also fairly low with -0,137 (notice: the Moran´s I for Auckland was -0,431). Thus the pattern continues, that was observed throughout all variables so far, the relationship type (positive or negative) is the same, but the degree to which the variable can explain the pattern is significantly lower when looking at the whole country.

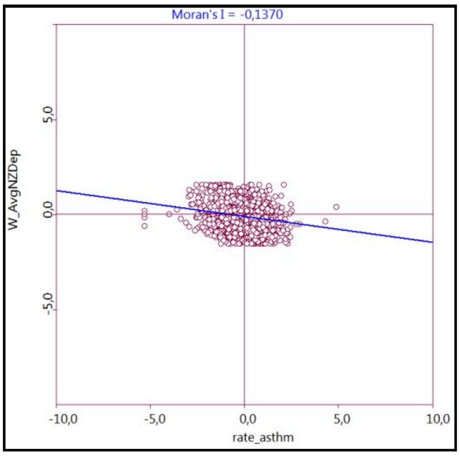


Figure 60 - Correlation between medicated Asthma and NZ Deprivation Index

The same applies for **number of bedrooms**. The highest adjusted R² is 0,02 as well and applies to multiple values. Again, for bedrooms per household no correlation analysis is executed due to the low adjusted R² within the regression analysis.

The adjusted R² for emissions from **domestic heating** (PM_{10}/ha) is 0,07 (positive relationship), thus more than twice as high as the model for the regional scale Auckland (0,03). The same picture is revealed when looking at the correlation analysis output (see the scatter plot to the right). The Moran´s I for the nationwide analysis is 0,222; compared to 0,066 for Auckland region only. This makes domestic heating the only variable up to this point, where a higher adjusted R² (regression analysis) and Moran´s I (correlation analysis) was calculated.

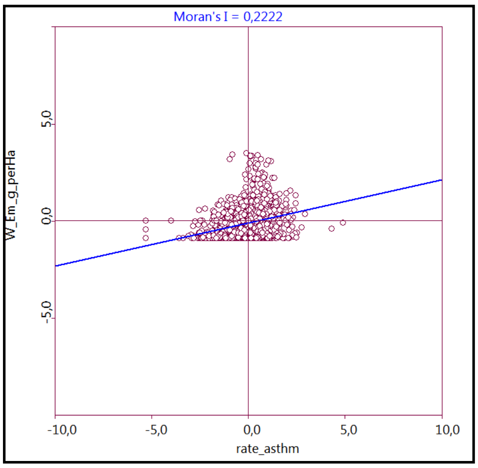


Figure 61 - Correlation between medicated Asthma and domestic heating emissions (PM/g)

Domestic heating emissions can (as mentioned earlier) also be considered as environmental variables. On a regional scale like for Auckland, the variation is smaller than for the national scale and also emissions disperse over space, which might explain the small relationship between medicated asthma and domestic heating emissions for the regional scale analysis. Table 4 shows the maximum, mean and standard deviation for emissions in g/ha coming from domestic heating (wood and coal).

Table 4 - Domestic heating (PM/g) statistics for New Zealand and Auckland

	New Zealand	**Auckland region**
Maximum	2365,67	990,46
Mean	285,056	377,70
Standard Deviation	319,09	255,71

The main observation is that the maximum for New Zealand is more than twice as high as for Auckland region. The 11 Census Areas with the highest values are all in the south in the city of Invercargill (in the very south) and Dunedin on the East Coast. So none of these extreme values are part of the regional scale model.

Population density was also used for the national analysis, as the density varies highly throughout the country. The findings show a positive relationship with an adjusted R² of 0,07; saying a higher density stands in context with an increased medicated asthma prevalence. The Moran´s I, calculated through correlation analysis is 0,2393.

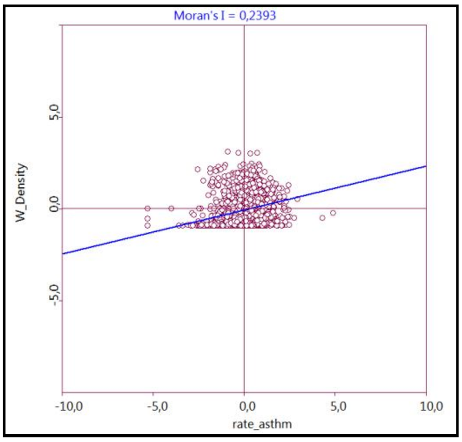


Figure 62 - Correlation between medicated Asthma and population density

Table 5 offers an overview of the variables and the characteristics that show the highest relationship with medicated asthma by adjusted R^2 and Moran´s I.

Table 5 - Summary of Regression and Correlation analysis for social variables – New Zealand

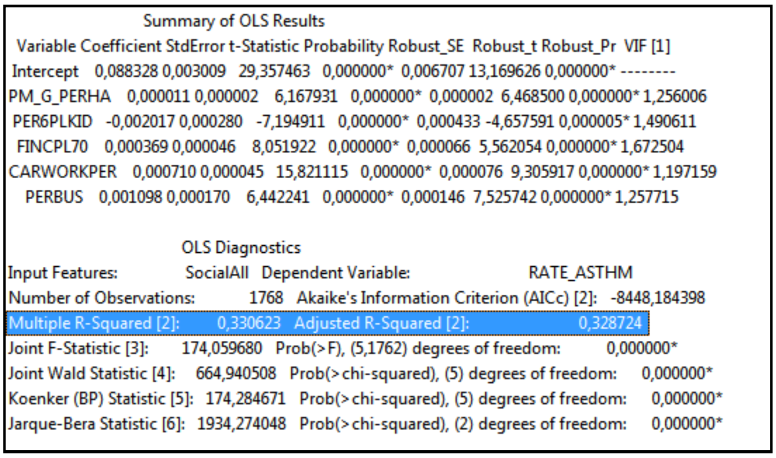
Variable	**Appropriate Category**	**Adjusted R^2**	**Moran´s I**
Age	**No relevant relationship found**		
Ethnicity	**Asians**	**0,06**	**0,2274**
Number of children	**2 children**	**0,10**	**0,1664**
	Over 6 children	**0,09**	**-0,2265**
Personal Income	**Over 30,000 NZD**	**0,13**	**0,2124**
	Over 50,000 NZD	**0,12**	**0,2351**
Family Income	**Over 70,000 NZD**	**0,14**	**0,2555**
	Over 50,000 NZD	**0,14**	**0,2260**
Employment Status	**No relevant relationship found**		
Travel means to work	**Drive by car**	**0,15**	**0,2864**
	Go by bus	**0,06**	**0,2430**
Qualification	**Postsecondary Degree**	**0,13**	**0,2610**
	Bachelor	**0,11**	**0,2807**
NZ Dep		**0,06**	**-01370**
Number of Bedrooms	**No relevant relationship found**		
Percentage with negative heating	**No relevant relationship found**		
Domestic Emissions		**0,07**	**0,2222**
Population Density		**0,07**	**0,2393**

Out of these findings, the Exploratory Regression tool is run once more to find out how the model is validated with the combination of the characteristics from the table, which are the most suitable variables.

The application of the tool shows that when using two variables the adjusted R^2 already rises up to 0,27 (percentage holding a bachelor degree and percentage driving to work by car). For 3 variables it reaches 0,30 (percentage of families with at least 6 children, percentage going to work by car and population going to work by bus). When 4 variables are used, only 1 percent more can be explained (adding family income of at least 70,000 NZD). The default settings, which also reflect the standard setting of the Ordinary Least Squares analysis, have a maximum use of 5 variables. The adjusted R^2 in this case is 0,33 through the combination of the variables: domestic heating emissions, households with at least 6 children, family income of at least 70,000 NZD, population going to work by car and population going to work by bus. Unlike with the model for the Auckland region, no model could pass the criteria for “Minimum adjusted R^2” > 0,5. The “Maximum coefficient p-value” criterion was met in 30% of the models and the “Maximum VIF value” criteria in 76% of the cases. As already seen in the regional analysis, none of the models could pass the “Minimum Jarque-Bera p-value” nor the “Minimum Morans I p-value”.

4.3.2.1.2 Ordinary Least Squares

The next step of the analysis process is to apply the Ordinary Least Squares method tool in ArcGIS 10 to the variables that were selected in the previous chapter. The model with the 5 most appropriate independent variables is executed: domestic heating emissions, households with at least 6 children, family income of at least 70,000 NZD, population going to work by car and population going to work by bus. The summary of the OLS results and the diagnostics are demonstrated in the box below. As the diagnostics part reaffirms the adjusted R^2 is 0,33 which means the 5 most suitable social variables together can explain 33% of the spatial pattern of medicated asthma of New Zealand. This is not even half of the value of the regional social model (adjusted R^2 0,72).



```
                    Summary of OLS Results
 Variable Coefficient StdError t-Statistic Probability Robust_SE  Robust_t Robust_Pr  VIF [1]
 Intercept    0,088328 0,003009   29,357463   0,000000*  0,006707 13,169626 0,000000* --------
PM_G_PERHA    0,000011 0,000002    6,167931   0,000000*  0,000002  6,468500 0,000000* 1,256006
 PER6PLKID   -0,002017 0,000280   -7,194911   0,000000*  0,000433 -4,657591 0,000005* 1,490611
 FINCPL70     0,000369 0,000046    8,051922   0,000000*  0,000066  5,562054 0,000000* 1,672504
CARWORKPER    0,000710 0,000045   15,821115   0,000000*  0,000076  9,305917 0,000000* 1,197159
  PERBUS      0,001098 0,000170    6,442241   0,000000*  0,000146  7,525742 0,000000* 1,257715


                         OLS Diagnostics
Input Features:            SocialAll   Dependent Variable:                   RATE_ASTHM
Number of Observations:         1768   Akaike's Information Criterion (AICc) [2]:   -8448,184398
Multiple R-Squared [2]:       0,330623   Adjusted R-Squared [2]:                   0,328724
Joint F-Statistic [3]:       174,059680   Prob(>F), (5,1762) degrees of freedom:          0,000000*
Joint Wald Statistic [4]:    664,940508   Prob(>chi-squared), (5) degrees of freedom:     0,000000*
Koenker (BP) Statistic [5]:  174,284671   Prob(>chi-squared), (5) degrees of freedom:     0,000000*
Jarque-Bera Statistic [6]:  1934,274048   Prob(>chi-squared), (2) degrees of freedom:     0,000000*
```

Figure 63 – Summary of OLS Results – Social Model – New Zealand

The Koenker-test for the study area of New Zealand tells, that heteroscedasticity is significant and stationarity does not apply (unlike for the model built for Auckland). That means that the Joint Wald Statistic is taken to validate the model statistical significance, which shows significance. The remaining two tests – the Koenker (BP) Statistic and the Jarque-Bera Statistic are both not meeting the requirements of a good model. The residuals are not randomly distributed.

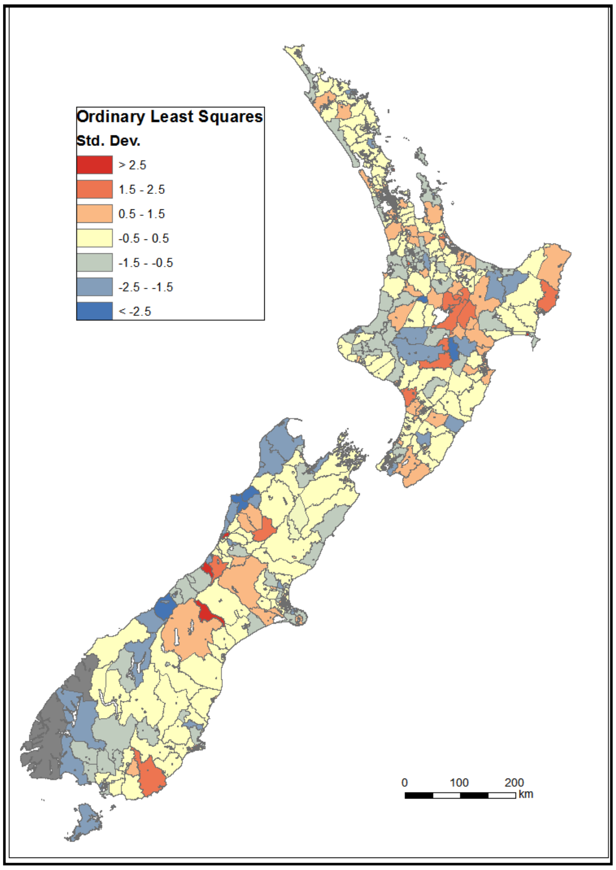


Figure 64 – Ordinary Least Squares Model – Social Characteristics – New Zealand

The map of New Zealand (Figure 64) shows the Standard Residuals and already reveals that there is some clustering across the country. To gain further clarity about spatial autocorrelation and clustering the Spatial Autocorrelation (Moran´s I) and Getis Ord GI* tools are used within ArcGIS 10. The Global Moran´s I Summary tells that the Moran´s Index is 0,135; the z-score is 12,104. This confirms that clusters do appear. With the local cluster analysis the location of these clusters is illustrated, which can be seen in Figure 65.

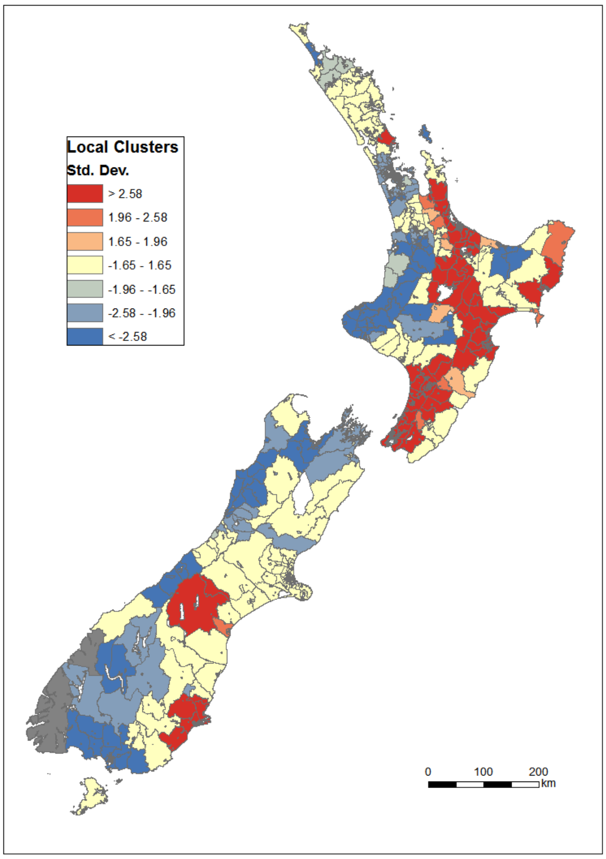


Figure 65 – Local Clusters of Standard Residuals (OLS) – Social Characteristics – New Zealand

The hot spots of both over- and under predictions are quite distinct. Especially in the North Island there is a vast stretch that goes from the Bay of Plenty and the area around Tauranga further south all the way to Lake Taupo to the east coast (Hawke´s Bay), where Napier and Gisborne are located and then further south to Wellington. On the other hand, the west coast shows “cold spots” on both, North Island and South Island as well. Furthermore some smaller hot spots on the North Island can be found on the north east as well as a smaller region north of Auckland. Hot spots on the South Island are located in the south east around Dunedin as well as the mountainous area in the centre of the South Island.

4.3.2.1.3 Geographically Weighted Regression

The same 5 variables that were extracted from the Exploratory Regression tool (domestic heating emissions, households with at least 6 children, family income of at least 70,000 NZD, population going to work by car and population going to work by bus) are used for the GWR method.

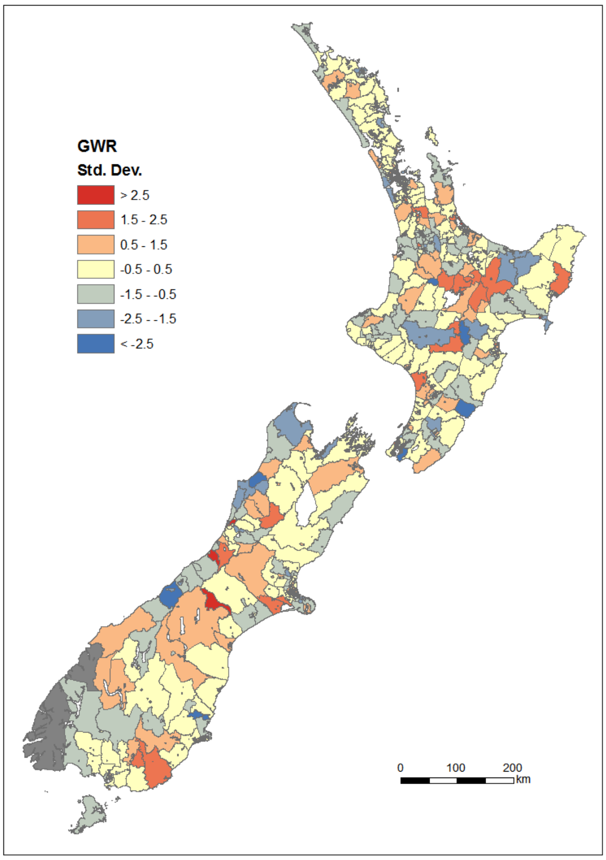


Figure 66 – Geographically Weighted Regression – Social Characteristics – New Zealand

Overall the output map from Geographically Weighted Regression shows a similar picture than the one from Ordinary Least Squares. What can be seen is that there are some minor differences within the areas of 0,5-1,5 / -1,5 - -0,5 (in the south west of the South Island/north east of the South Island as well as the north and south east of the North Island. Furthermore the OLS output map shows a positive standard deviation in the central east coast of the North Island (to the east of the Taupo Volcanic Zone), whereas GWR shows a negative standard deviation. The adjusted R² is 0,49 (for Auckland region it was 0,73).

4.3.2.1.4 Conclusion – Social Characteristics New Zealand

At this point of study, some areas already can be explained well through the social characteristics model, while others still show major deviations. First and foremost the area of the Taupo Volcanic Zone definitely seems to be influenced by some key factors, which increase the rate of asthma compared to the rest of New Zealand. The same applies to some Census Area Units in the mountainous areas of the South Island. The opposite are CAUs on the west coast (including north and south) of the South Island, but also the central west coast of the North Island and larger parts further south of the Taupo Volcanic Zone. In the following, environmental variables are looked at, to try to optimize the model and extract further variables that can explain and justify the medicated asthma prevalence in New Zealand.

4.3.2.2 Environmental Variables

This chapter will provide insight about how the climate and other variables of the environment of New Zealand are influencing the spatial distribution of medicated asthma prevalence all across the country.

4.3.2.2.1 Exploratory Regression/Correlation Analysis

From the **LENZ data**, the highest adjusted R² was calculated for water balance radiation (0,09), followed by average elevation (0,07) and slope (0,07). When combining two variables the adjusted R² is 0,11. The 3 variables with the highest R² are implemented for the multivariate correlation analysis in GeoDa (the Moran´s I scatter plot: water balance radiation on the left, average elevation in the center and average slope on the right side).

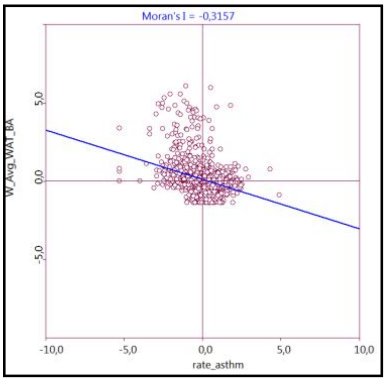


Figure 67 – Correlation between medicated Asthma and water balance radiation

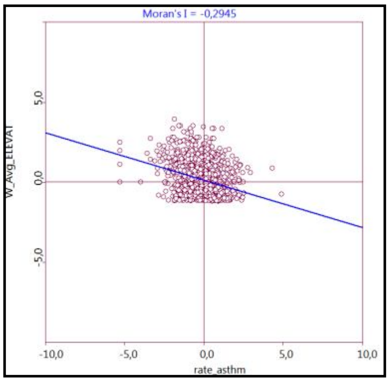


Figure 68 - Correlation between medicated Asthma and average elevation

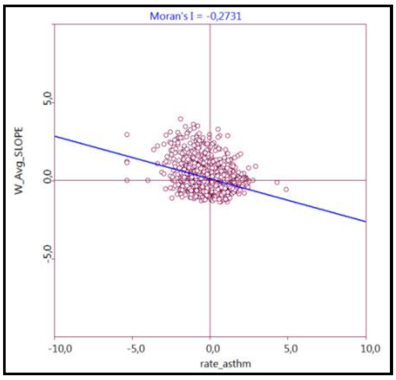


Figure 69 – Correlation between medicated Asthma and average slope

The relationship with medicated asthma rate is negative for all 3 variables. This means higher water balance radiation correlates with smaller asthma prevalence, higher located areas show a smaller rate of medicated asthma and Census Area Units that have a steeper terrain tend to have smaller rate of medicated asthma.

The variable **rainfall** has an adjusted R² of 0,10 when implemented to Exploratory Regression. From the correlation analysis the information extracted is, that the relationship is negative (higher rainfalls correlate with a smaller rate of medicated asthma) and the Moran´s I is -0,386. This outcome coincides with the study from Hales and Lewis *et al*. (1998).

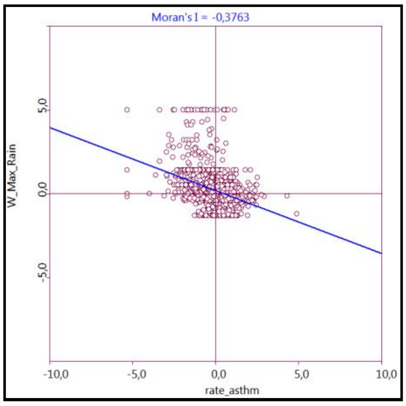


Figure 70 - Correlation between medicated Asthma and rainfall

Wind speed can only explain very little of the spatial distribution of medicated asthma. The adjusted R² is 0,04 for the average wind speed in m/s and 0,02 for the maximum wind speed. Therefore no correlation analysis was applied.

Average urbanization can explain 21% of the spatial pattern of medicated asthma across New Zealand (adjusted R²: 0,21). The relationship is negative and the correlation, expressed through the Moran´s I, is -0,420. This means that higher urbanization correlates with higher rates of medicated asthma (as the classification ranges from 1 with highest degree of urbanization to 6 with the lowest urbanization level).

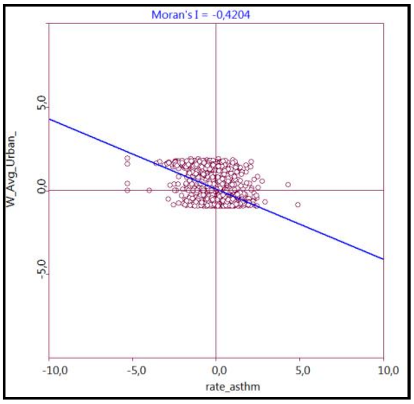


Figure 71 - Correlation between medicated Asthma and average urbanization

For **each land cover class** (main category) the percentage of the area per CAU was used to analyze the relationship with medicated asthma. Exploratory Regression´s output shows that for percentage forest and percentage artificial surface the highest adjusted R² is calculated (both 0,08). While the relationship between asthma prevalence and proportion of artificial surfaces is positive (higher percentage of artificial surface goes hand in hand with higher medicated asthma rate), the relationship between percentage of forest areas and medicated asthma is negative.

The Moran´s I of Multivariate LISA, calculated through GeoDa is 0,267 for percentage artificial surface and -0,306 for percentage forest area per CAU as illustrated below through the Moran´s I scatter plot.

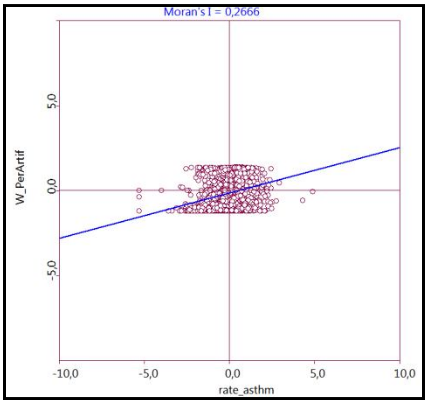


Figure 72 - Correlation between medicated Asthma and percentage artificial surface

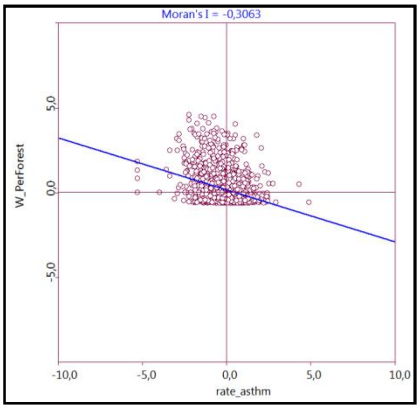


Figure 73 - Correlation between medicated Asthma and percentage forest area

For **air pollution** a maximum adjusted R² is calculated for the category PM$_{2.5}$ with 0,10. All categories including emission sources were implemented to the Exploratory Regression tool, so the second highest R² is for natural sources with 0,08; followed by PM$_{10}$ with 0,07. When taking a model with 2 variables the highest adjusted R² is computed when combining PM$_{10}$ and PM$_{2.5}$.

All 3 subcategories of the air pollution variable are tested in GeoDa for correlation. As the Moran´s I scatter plots below show, the Moran´s I for PM$_{2.5}$ is 0,299. With a positive relationship, as expected higher PM$_{2.5}$ rates correlate with higher rate of medicated asthma. For the percentage of natural sources to PM emissions the Moran´s I is -0,262. So that shows that it is more likely that the prevalence of medicated asthma is more influenced by emissions caused through other causes (like industries, motor vehicles, outdoor burnings and domestic emissions). The lowest Moran´s I (of the selected 3 variables) is calculated for PM_{10}, which coincides with the result of the regression analysis. The Moran´s I is 0,238.

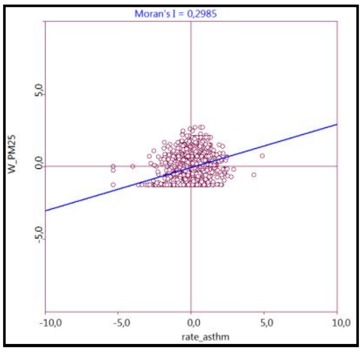


Figure 74 - Correlation between medicated Asthma and $PM_{2.5}$ rate

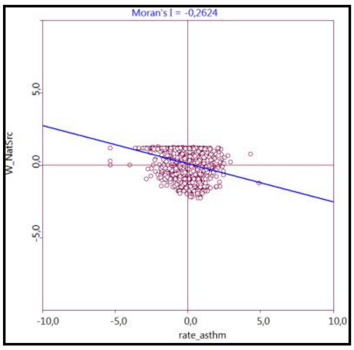


Figure 75 - Correlation between medicated Asthma and percentage natural emission sources

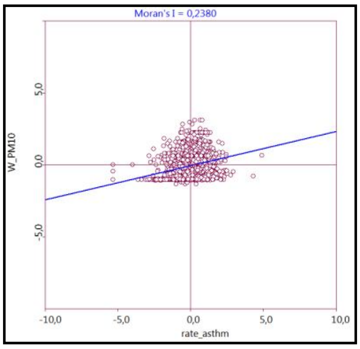


Figure 76 - Correlation between medicated Asthma and PM_{10} rate

The results from analyzing the **roads (density)** data show that the maximum adjusted R² is at 0,08. The Moran´s I for density of roads is 0,283. Which means the expected positive relationship can be confirmed through the analysis.

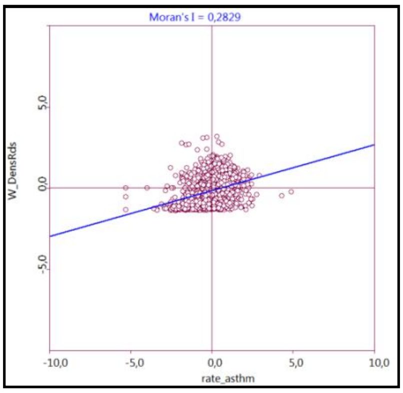


Figure 77 - Correlation between medicated Asthma and road density

Table 6 provides a summary for the results of the environmental variables applied on the national scale.

Table 6 - Summary of Regression/ Correlation Analysis – Environmental Variables – New Zealand

Variable	Appropriate Category	Adjusted R^2	Moran´s I
Water Balance		**0,09**	**-0,3157**
Slope		**0,07**	**-0,2725**
Elevation		**0,07**	**-0,2945**
Rainfall		**0,10**	**-0,386**
Wind speed	**No relevant relationship found**		
Urbanization		**0,21**	**-0,4204**
Land cover	**Artificial Surface**	**0,08**	**0,2666**
	Forest Area	**0,08**	**-0,3063**
Air pollution	**$PM_{2.5}$ level**	**0,10**	**0,2985**
	Natural PM Source	**0,08**	**-0,2624**
	PM_{10} level	**0,07**	**0,2380**
Roads	**Density of all roads**	**0,08**	**0,2829**

Urbanization is the only variable that has an adjusted R^2 of over 0,20 and a Moran´s I that exceeds 0,4. All these variables are now combined in the Exploratory Regression tool in ArcGIS with the settings that are used for Ordinary Least Squares as well.

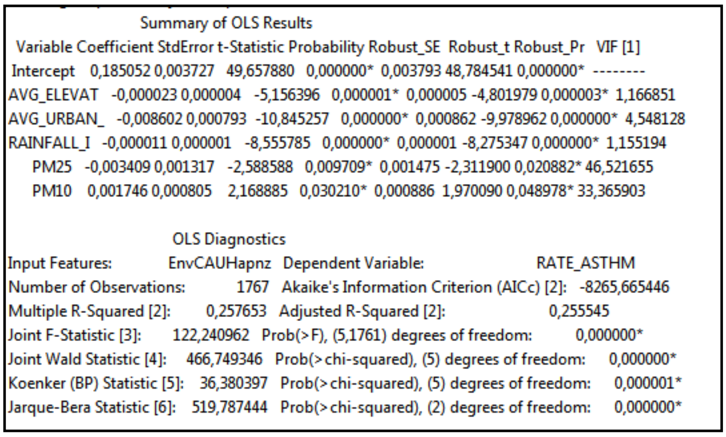
That means a maximum combination of 5 variables is used. The adjusted R^2 that is hereby extracted is 0,26 which is reached through three possible combinations:

- Elevation, Urbanization, Rainfall, $PM_{2.5}$, $PM_{10.0}$
- Elevation, Urbanization, Rainfall, Percentage Artificial Surface, Road Density
- Elevation, Slope, Urbanization, Rainfall, Percentage Artificial Surface

The first of these combinations is now implemented into Ordinary Least Squares to receive a visual output as well.

4.3.2.2.2 Ordinary Least Squares

The adjusted R² of 0,26 is small, even though a broad spectrum of environmental variables was included, of which the 5 most suitable factors were selected.



```
                  Summary of OLS Results
 Variable Coefficient StdError t-Statistic Probability Robust_SE  Robust_t Robust_Pr  VIF [1]
 Intercept   0,185052 0,003727  49,657880  0,000000*  0,003793 48,784541 0,000000*  --------
AVG_ELEVAT   -0,000023 0,000004   -5,156396  0,000001*  0,000005 -4,801979 0,000003*  1,166851
AVG_URBAN_   -0,008602 0,000793  -10,845257  0,000000*  0,000862 -9,978962 0,000000*  4,548128
RAINFALL_I   -0,000011 0,000001   -8,555785  0,000000*  0,000001 -8,275347 0,000000*  1,155194
    PM25   -0,003409 0,001317   -2,588588  0,009709*  0,001475 -2,311900 0,020882* 46,521655
    PM10    0,001746 0,000805    2,168885  0,030210*  0,000886  1,970090 0,048978* 33,365903

                      OLS Diagnostics
Input Features:           EnvCAUHapnz  Dependent Variable:                     RATE_ASTHM
Number of Observations:          1767  Akaike's Information Criterion (AICc) [2]:  -8265,665446
Multiple R-Squared [2]:      0,257653  Adjusted R-Squared [2]:                   0,255545
Joint F-Statistic [3]:     122,240962  Prob(>F), (5,1761) degrees of freedom:         0,000000*
Joint Wald Statistic [4]:   466,749346  Prob(>chi-squared), (5) degrees of freedom:    0,000000*
Koenker (BP) Statistic [5]:  36,380397  Prob(>chi-squared), (5) degrees of freedom:    0,000001*
Jarque-Bera Statistic [6]:  519,787444  Prob(>chi-squared), (2) degrees of freedom:    0,000000*
```

Figure 78 - Summary of OLS Results – Environmental Model - New Zealand

The Koenker (BP) Statistic test is significant, which means as already observed for the social model that there is no stationarity. The Joint Wald Statistic test is significant, which evaluates the model significance. The Jarque-Bera test result shows that the residuals are not normally distributed, so still at least one key variable must be missing. Whether or not this problem can be solved will be tested when combining social and environmental variables under the chapter 4.3.2.3 “National Analysis Model”.

The map of standard residuals of the Ordinary Least Squares output shows that clustering can be found. Apparently most of the areas that have under predictions are the same as for the social variables model, in particular the central mountainous area of the South Island or the area north east of lake Taupo, the area around Auckland and the south west tip of the North Island (DHB Capiti and Coast). The same can be said for under prediction, which are in both cases found for South Island on the south and north east, as well as the central coastal areas; and on the North Island especially south west of the Lake Taupo. The summary of Spatial Autocorrelation (Moran´s I) says that the z-score is 14,36 and the Moran´s I is 0,160. That shows that clustering appears to a higher degree than the model for social variables.

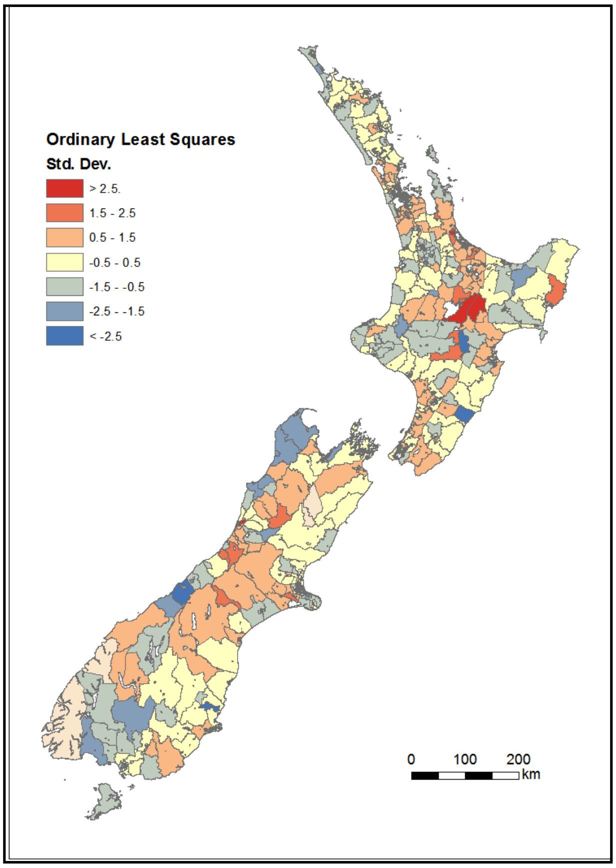


Figure 79 – Ordinary Least Squares Model – Environmental Characteristics – New Zealand

The Hot Spot Analysis (Figure 80) shows that the environmental model has fewer hot spots in the area at the DHB Mid Central and the southern Hawke´s Bay DHB compared to the social model. Nevertheless hot spots do occur all around the direct vicinity of Lake Taupo and north of Lake Taupo in the area of the city Tauranga, just like for the model with social characteristics. While both models have cold spots on the west coast of the North Island, the over predictions are more distinct for the environmental model. Especially on the South Island the difference between the two models are higher. The central mountainous area of the environmental model shows a large area of hot spots. These also reach the west coast in the central northern parts and the east coast further south between the cities of Dunedin and Christchurch (Christchurch itself is in a cold spot zone). The most dominant hot spot seem to be north east of Lake Taupo in the Taupo Volcanic Zone. As already mentioned there are certain air pollutants emitted through bores and thermal activity. These could not be covered in the national wide analysis. There is no nationwide monitoring of air pollutants such as SO_2 or H_2S. To still cover this aspect in this study, chapter 4.3.3 deals with the mapping of bores and in the Taupo Volcanic Zone.

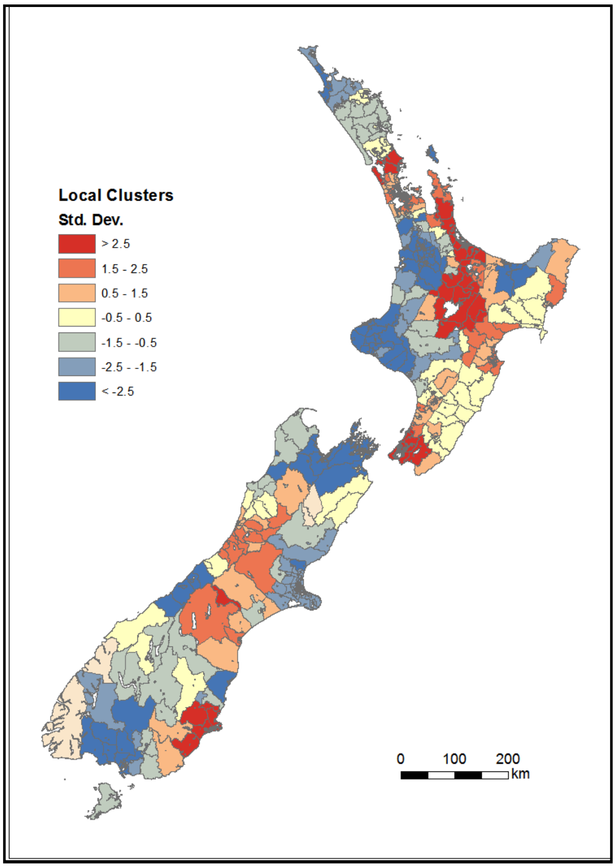


Figure 80 – Local Clusters of Standard Residuals (OLS) – Environmental Characteristics – New Zealand

4.3.2.2.3 Geographically Weighted Regression

To finish the subchapter about the model with environmental variables, a Geographically Weighted Regression is executed. The variables chosen are: elevation, urbanization, rainfall, percentage artificial surface, road density.

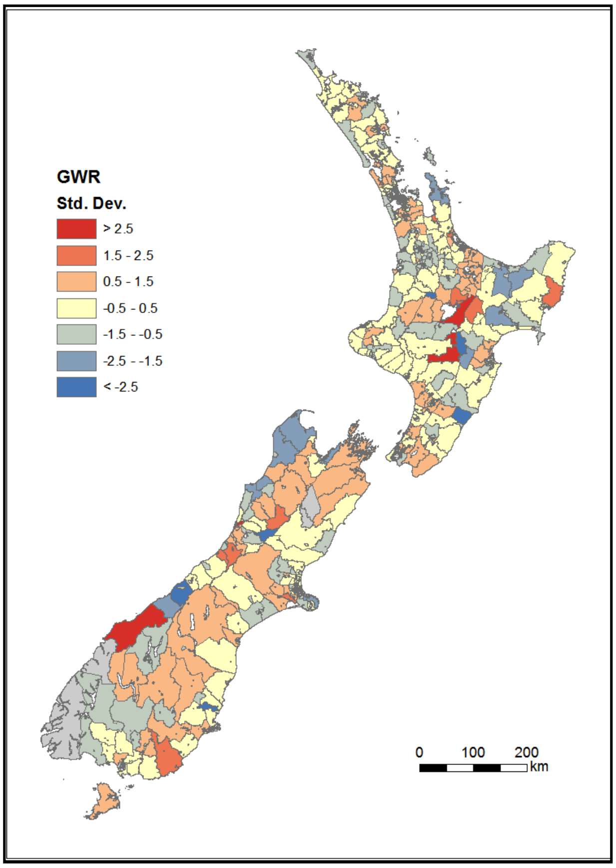


Figure 81 – Geographically Weighted Regression – Environmental Characteristics – New Zealand

The output map of Geographically Weighted Regression and the Ordinary Least Squares maps are very similar. Overall only slight differences can be found, such as a stronger positive standard deviation on the west coast of the South Island and in particular in the central southern part of the South Island. On the opposite a few CAUs are shaded in blue on the North Island (south of Lake Taupo and the area around New Plymouth on the west coast) on the Ordinary Least Squares output map, while they are shaded in yellow for the Geographically Weighted Regression output. The output table shows that the adjusted R² is higher using GWR (0,33) compared to OLS (0,26). Less can be explained using environmental variables compared to using social variables (the adjusted R² was 0,49).

4.3.2.3 National Analysis Model

As both, the environmental and social model, can only partially explain the spatial distribution of medicated asthma, this chapter is now combining the two models into one. However what has been noted already in the previous chapters, is that both models have similar under and over predictions (in particular on the west coast of the South Island where over predictions are dominating and north/east of Lake Taupo with distinct under predictions on the North Island), it can be already expected that even the combination of both models will not be able to fully explain the pattern.

First of all, with Exploratory Regression the top 5 variables are determined, with which later on OLS and GWR are executed. For this, the variables that were listed within the Tables 5 and 6 are used as input for explanatory variables.

4.3.2.3.1 Exploratory Regression

The Exploratory Regression tool has determined the 3 best models, which all have an adjusted R^2 of 0,36:

- percentage 6 children and more, percentage at least 50,000 NZD personal income, percentage of working population going to work by car, urbanization, rainfall
- percentage 6 children and more, percentage at least 70,000 NZD family income, percentage of working population going to work by car, urbanization, rainfall
- percentage 2 children, percentage at least 70,000 NZD family income, percentage of working population going to work by car, urbanization, rainfall

So all 3 have a similar choice of variables which are only varying for the number of children and the type of income, but they all select both social and environmental variables. However no combination reaches an adjusted R^2 of over 0,5. The same applies to the Jarque-Bera and the Moran´s I test, both signifying that at least 1 key variable is still missing. As already mentioned the output map for residuals showed similar trends for both environmental and social variables, which may be the reason that even a combination does not contribute to a notably higher adjusted R^2 than when using only social or only environmental variables.

4.3.2.3.2 Ordinary Least Squares

For the model the first set of variables (percentage 6 children and more, percentage at least 50,000 NZD personal income, percentage of working population going to work by car, urbanization, rainfall) are selected to perform the Ordinary Least Squares analysis. As the Exploratory Regression already showed, the adjusted R² is 0,36 for this combination, which is the maximum that can be achieved with the given variables. The output map of the national model shows just like in the previous models for social and environmental variables separately that there are still high positive standard residuals in the North Island especially in the Taupo Volcanic Zone, as well as the north eastern coastal areas in the DHB Tairawhiti, whereas the south west of the Taupo area is shaded in blue. The South Island also has basically the same pattern of standard residuals as was already observed for the single models.

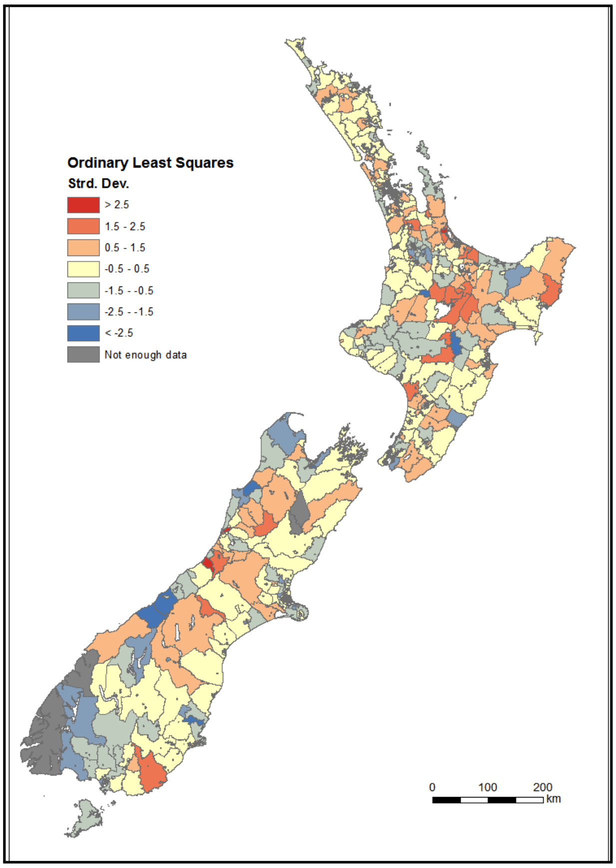


Figure 82 – Ordinary Least Squares – National Model – New Zealand

The Global Moran’s summary now determines a Moran´s Index of 0,136 and a z-score of 12,22; which is quite similar to the social model. Clustering definitely can still be found even after combining variables of both models.

The Local Cluster map also shows the same what could already be observed in the previous models. Under predications occur north of Auckland, the north central coast (DHB Tairawhiti) as well as the north east coast of the North Island, the region of the DHB Wairarapa in the south east of the North Island and most of all the broad stretch from the north of Lake Taupo all the way to Hawke´s Bay. On the South Island under predictions are around the city of Dunedin on the south east, as well as the central mountain area. The South Island is more dominated by over predictions on the eastern coast and on the west mostly around Christchurch. On the North Island over predictions are mainly on the west coast in the DHB of Taranaki, on an area all around Hamilton, as well as some CAUs east of Tauranga (which is a hot spot area itself). Even though cold spots are found on the west coast of the North Island, these are less dense than for the environmental model.

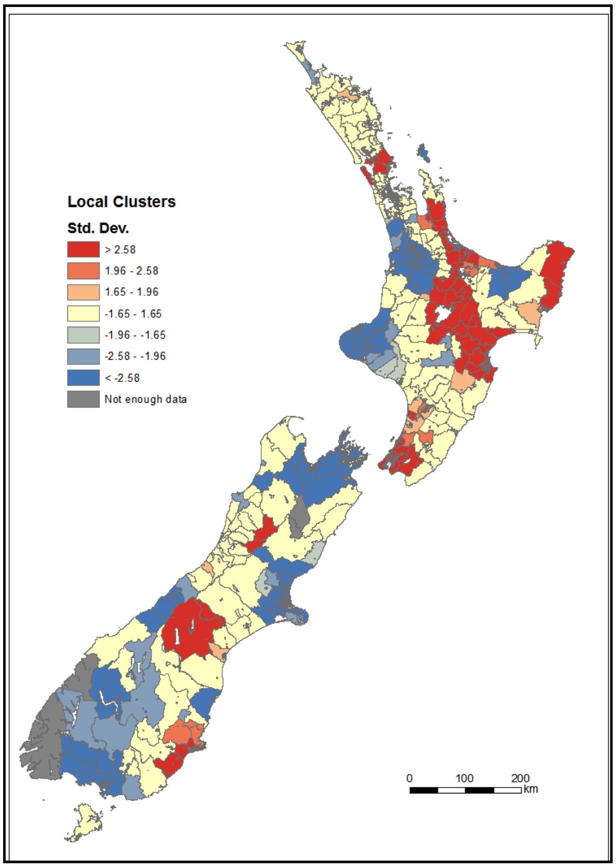


Figure 83 – Local Clusters of Standard Residuals (OLS) – National Model – New Zealand

4.3.2.3.3 Geographically Weighted Regression

For the Geographically Weighted Regression model the variables percentage of population with a personal income of at least 50,000 NZD, percentage of working population going to work by car, rainfall, urbanization and percentage of household with at least 6 children are selected. The adjusted R^2 for the model is 0,45; which means that 45% of the spatial distribution of medicated asthma can be explained through the 5 most suitable variables that were available for the regression/correlation analysis.

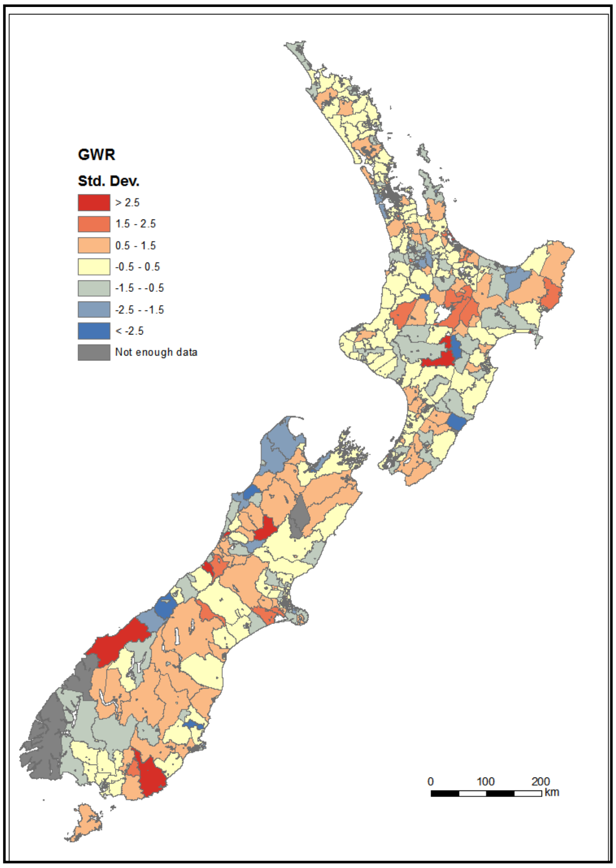


Figure 84 – Geographically Weighted Regression – National Model – New Zealand

The map (Figure 84) still shows many over and under predictions throughout the country, as already noted in the Ordinary Least Squares results. That means that important explanatory variables could not be covered with the available data. Possibly even other analysis methods would be necessary to reduce the over and under predictions and reduce the clustering of standard residuals.

4.3.3 Additional Region

4.3.3.1 Geothermal Bores Taupo Volcanic Zone

As already mentioned the factor air pollution could only be covered to a limited level in the regression analysis part. To pick up the fact that areas with geothermal activity and bores are suspect to produce gases that harm the respiratory tract and thus are also critical for asthmatics or to sensitize people for asthma, this chapter is looking at the localization of thermal bores in New Zealand, which are all situated in the Taupo Volcanic Zone. Between Taupo and Rotorua there are 18 geothermal bores (see Figure 85).

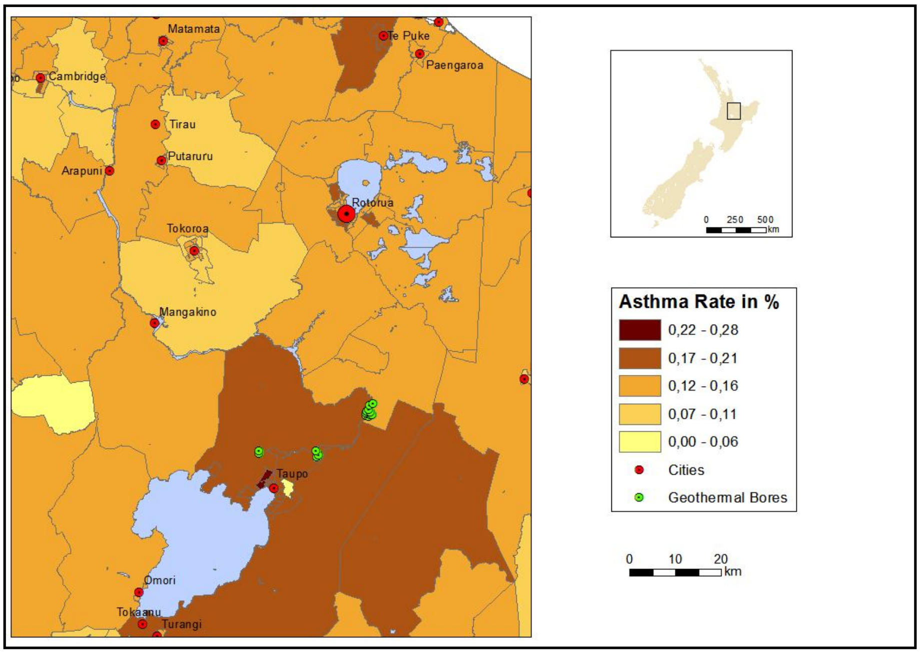


Figure 85 - Geothermal Bores of the Taupo Volcanic Zone and Asthma prevalence distribution.

The bores are rather close to the city of Taupo. Five bores are located in Census Area Units with asthma prevalence of 17 to 21%. Whereas 13 bores are situated in a CAU with prevalence of 16% (above the national mean). However these bores are very close to neighboring CAUs with even higher asthma rates (18,4% and 17,5%). This observation unfortunately cannot be included to the regression analysis, but certainly rises the already assumed relation that the gases emitted from geothermal bores influence the respiratory system and as a consequence also stands in relation to asthma. This zone is exactly the area which has already proven to be a major hot spot throughout all the models of the regression analysis and could not be explained through any of the variables that were handled in the regression and correlation analysis process.

5 Conclusion

This chapter offers a summary about the findings and what conclusions can be drawn from the results. Furthermore limitations and possibilities for further research are discussed.

Overall the study shows that medicated asthma prevalence in New Zealand is significantly clustered, however there was no model found that can fully explain the pattern. The analysis showed that the regional model is more successful than the national scale. For the social characteristics model 0,72% (through Ordinary Least Squares analysis) / 73% (through Geographically Weighted Regression analysis) of the pattern could be explained for the Auckland region. This alone would fulfill the requirements of a good model, not though the Jarque-Beta and Moran´s I. The problem therefore is that the Census Area Units where asthma rates are well explained through the variables are not normally distributed over the study area. This aspect appears for all the models. That means that at least one main explanatory variable is still missing, even for the national model where social and environmental variables are included. Despite, that more attributes are included for the national analysis, the percentage that can be explained through the 5 most suitable variables is only 45% taking the results from Geographically Weighted Regression or 36% from the Ordinary Least Squares Regression, a global model which does not consider that relationships between dependent and independent variables may vary throughout the study area. The Geographically Weighted Regression is therefore more suitable as an orientation. Here it has to be considered that the variables chosen for Geographically Weighted Regression are based on the Exploratory Regression results, which again are orientated to build a model for Ordinary Least Squares. The combination of variables chosen for the social model through OLS result in an adjusted R^2 of 0,33, while the combination of social and environmental variables have an adjusted R^2 of 0,36. However for GWR the adjusted R^2 for the these exact same variables is 0,49 for the social model but only 0,45 for the national model. This is because the variable selection is pursued to build the best possible model for Ordinary Least Squares method. Table 7 summarizes all the adjusted R^2 results of the different models and scales.

Table 7 - Adjusted R² Results Summary

Territory and spatial variables	Methods and results	
	OLS	GWR
Auckland (Social)	**0,72**	**0,73**
NZ (Social)	**0,33**	**0,49**
NZ (Environmental)	**0,26**	**0,33**
NZ (Combined)	**0,36**	**0,45**

As the influence of the individual variables was already discussed in detail throughout the practical part, these are not mentioned here furthermore. However what was surprising in the results is that partially a contradiction to previous studies was observed. For instance asthma is seen as a disease that is more prevalent in lower social classes with poor housing conditions. In this study however, a positive relationship was found for higher income families/persons. For this reason it is important to point out, that this study may diverge as it deals with medicated asthma and families or individuals that are wealthier can use services as going to the GP or using preventive medications more often than those who only use health care services in severe cases. With little financial means, the health care access is limited. So there may be a dark figure of asthmatics that is higher in poorer social income areas than in high social income areas. This could also mean that when using hospitalization data wealthier classes could be underrepresented as preventive and constant health care might often prevent hospitalization and severe asthma attacks are less. Considering this, questionnaires would be more eligible to use to receive the indicator asthma prevalence. Certainly all of these possible methods do have their strength and weaknesses. However, it could also be that there are relationships between the independent variables, for example that lower social economic classes live more in urban areas where pollution is higher. This would mean that not necessarily the financial situation is the primary cause to higher or lower medicated asthma prevalence, but the urban environment. Correlation does not automatically mean causality. Some of the independent variables were examined for correlation in GeoDa (Multivariate LISA) to see if they show some relationship. It is tested whether either urbanization or $PM_{2,5}$ levels have a relationship on family/personal income, NZ Deprivation Index, education and ethnicity. The categories used are the ones with the highest adjusted R² from the social variables of New Zealand (Table 5). Table 8 shows the Moran´s I from each scatter plot.

Table 8 – Correlation between Urbanization/$PM_{2,5}$ levels and social variables

	Moran´s I Urbanization	**Moran´s I $PM_{2,5}$**
Proportion Asian	-0,432	0,328
Personal Income > 30,000 NZD	-0,083	-0,009
Personal Income > 50,000 NZD	-0,131	0,014
Family Income > 50,000 NZD	-0,124	0,036
Family Income > 70,000 NZD	-0,192	0,069
Postsecondary Degree	-0,254	0,148
Bachelor Degree	-0,350	0,235
NZ Dep Index	-0,108	0,120

It is apparent that some relationships are fairly strong while others show practically no relationship. A strong relationship can be found between urbanization and Asian population as well as urbanization and percentage of population with a Bachelor Degree. As the major urban areas have the value "1" within the attribute table and the most rural areas have the value "6", it means that most urbanized areas have a high proportion of Asians and population with Bachelor Degree. The same is noticed for income, however the Moran´s I is smaller for the income attributes. The $PM_{2,5}$ levels show a similar situation, but the relationship is weaker than for urbanization. The conclusion from this is that not only the variables of income, deprivation, ethnicity or qualification causes higher or lower asthma prevalence but also the spatial distribution and the resulting environmental influence (such as air pollution).

Another limitation for this study is that only residence is used as a factor. That means that the environmental influence that a child might have when he or she is visiting a school in another CAU cannot be included. Also the location of work place is not considered (in case it is in another CAU, where individuals spend a lot of time). In addition only means and averages of the CAUs could be taken as indication, but not individual data about the actual asthmatics is available. This is in particular a limitation for the social characteristics, not so much for the environmental variables. Information about lifestyle of individuals like eating habits or physical fitness is therefore not available, but may influence asthma. This kind of data can rather be included in other types of study, which use sample questionnaires instead of the entire rate of an area taken from official sources. In addition certain factors like psychology or personal hygiene can hardly be included in either approach. Three major missing or insufficient available factors are air pollution, dust mites and pollen levels. All three are key suspects to determine asthma. Air pollution was covered in the analysis, but due to the availability only as PM_{10} and $PM_{2.5}$ indicators. So far measuring sites are run by regional councils and therefore the conditions vary highly throughout the country (years of measurement, density of stations, air pollutants measured). In particular pollutants such as H_2S and SO_2 could be a key explanatory variable for New Zealand given the clustering around Lake Taupo. The second aspect of dust mites as a prime allergen (Wickens, 1997) in particular in mattresses also could not be included for this study. Only aspects like humidity, temperature, bedrooms, heating were used as possible indirect influencing factors for high/low dust mite levels. In some other studies (Carrie & Cordon, 1986 as well as Celenza *et al.*, 1996, according to Hales *et al.*, 1998 a correlation with humidity was more distinctive as for this one. One reason might be that, New Zealand has high humidity all year round and therefore dust mites find good conditions to relative humidity in New Zealand anyways. Therefore this is not the limitation factor for house dust mites in New Zealand. In Wellington for example – where the study of Wickens (1997) was carried out, the mean relative humidity ranges from 79,8% in summer to 85,6% during the winter. The fluctuation over the seasons is so little, that mites have good conditions (regarding relative humidity) all year round. Stracher and Sanders (1989) as well as Williamson *et al.* (1997) also tested humidity as possible influencing factor on asthma and did not find correlation either. And finally pollen levels were tried to gather through previous studies, but no material was found. There is information about seasonal variance available but not about spatial variance throughout New Zealand. As pine pollen can cause/ aggravate asthma (www.acaai.org) the proportion of area with pine tree forests was included in the environmental variables, but this factor actually showed little relationship to asthma with this approach of trying to include the attribute of pollen in the study.

Nonetheless this study achieved to include a broad variety of explanatory variables that are possible trigger for asthmatics or may even sensitize for asthma. All the attributes come from credible sources. In particular the dependent variable “medicated asthma” or “Tracker” is highly reliable and has the advantage that not only severe cases that are hospitalized are included as in most studies the case, but also all other recorded events where medication is bought or a GP is consulted are considered. Using different type of analysis and not only regression analysis also reaffirm the findings (through correlation analysis) or include factors that cannot be examined through regression analysis, such as thermal bores (through disease mapping). Using a regional and a national model together is a good way of exploring differences in the influence when looking at different scales. In this case (for the social model) similarities were found partially (such as family/personal income trends, means of travelling to work and number of children) but not for all variables (e.g. age, ethnicity, employment status or NZ Deprivation Index). That shows that it is worth to look at various scales when doing such an analysis. Therefore bigger scale analysis is of high use when approaching spatial variables that may not be used in regression analysis but are examined through mapping only.

All in all the study provided a substantial look on the multiple variables that were accessible and provides insight on what further analysis would be useful. First of all a collection of data about spatial distribution of pollen would be desirable to help the health care industry to evaluate the actual correlation and risks. Secondly further data about air pollution and possibly a more standardized system of measuring can help in many health issues, not only asthma. An optimal source of data certainly would be if more information about personal situation would be available that makes it possible to pursue an analysis that can respect individual data for all cases (not only sample data collected through questionnaires).

As a final remark it is left to say, that spatial analysis and the use of Geographical Information Systems in health care topics has lead to an immense potential of finding coherence of disease and spatial factors. With the increased availability of all kinds of data throughout the world the possibilities are rising constantly which helps in the end health care providers and patients alike.

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