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APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM AND MODELLING IN HEALTH IMPACT ASSESSMENT FOR URBAN ROAD MOBILITY IN VIETNAM

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If we hold on together,

our dreams will never die

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APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM AND MODELLING IN HEALTH IMPACT ASSESSMENT FOR URBAN ROAD MOBILITY IN VIETNAM

VU VAN HIEU

Abstract

Transport is an essential sector in modern societies. It connects economic sectors and industries. Next to its contribution to economic development and social interconnection, it also causes adverse impacts on the environment and results in health hazards. Transport is a major source of ground air pollution, especially in urban areas, and therefore contributing to the health problems, such as cardiovascular and respiratory diseases, cancer, and physical injuries.

This thesis presents the results of a health risk assessment that quantifies the mortality and the diseases associated with particulate matter pollution resulting from urban road transport in Hai Phong City, Vietnam. The focus is on the integration of modelling and GIS approaches in the exposure analysis to increase the accuracy of the assessment and to produce timely and consistent assessment results. The modelling was done to estimate traffic conditions and concentrations of particulate matters based on geo-references data. A simplified health risk assessment was also done for Ha Noi based on monitoring data that allows a comparison of the results between the two cases. The results of the case studies show that health risk assessment based on modelling data can provide a much more detail results and allows assessing health impacts of different mobility development options at micro level.

The use of modeling and GIS as a common platform for the integration of different assessments (environmental, health, socio-economic, etc.) provides various strengths, especially in capitalising on the available data stored in different units and forms and allows handling large amount of data. The use of models and GIS in a health risk assessment, from a decision making point of view, can reduce the processing/waiting time while providing a view at different scales: from micro scale (sections of a city) to a macro scale. It also helps visualising the links between air quality and health outcomes which is useful discussing different development options.

However, a number of improvements can be made to further advance the integration. An improved integration programme of the data will facilitate the application of integrated models in policy-making. Data on mobility survey, environmental monitoring and measuring must be standardised and legalised. Various traffic models, together with emission and dispersion models, should be tested and more attention should be given to their uncertainty and sensitivity.

Keywords: Health Impact Assessment, GIS, modelling, health outcomes, air pollutants, PM_{10}, urban road transport, Hai Phong, Hanoi, Vietnam.

Resumo

O transporte é um sector importante nas sociedades modernas ligando as actividades económicas e o sector industrial. Contudo, a par do seu contributo para o desenvolvimento económico e a conexão social, também causa impactos adversos no ambiente e resulta em perigos para a saúde. O transporte é uma importante fonte de poluição do ar, especialmente em áreas urbanas, e desse modo contribui para problemas de saúde, tal como doenças cardiovasculares e respiratórias, cancros e lesões físicas.

Esta tese apresenta o resultado de uma avaliação ao risco de saúde que quantifica a mortalidade e as doenças associadas à poluição do ar por partículas resultante dos transportes urbanos na cidade de Hai Phong, no Vietnam. O foco da tese é a integração das abordagens e modelação dos sistemas de informação geográfica (SIG) para melhorar a análise de exposição e aumentar a precisão da avaliação, produzindo resultados consistentes e permitindo intervir atempadamente no sentido de minimizar o seu efeitos. A modelação foi feita para estimar as condições de tráfego e da concentração de partículas com base em dados georreferenciados. Uma avaliação simplificada do risco de saúde também foi feita para a cidade de Ha Noi, com base em dados existentes de monitorização do tráfego, permitindo a comparação dos resultados entre os dois casos. Os resultados dos estudos de caso mostram que a avaliação de risco para a saúde com base em dados de modelação pode fornecer resultados mais detalhados e permite avaliar os impactos na saúde de diferentes opções de mobilidade ao nível micro.

O uso dos SIG e da modelação como uma plataforma comum para a integração de diferentes avaliações (ambientais, socioeconómicas, de saúde, etc.) apresenta inúmeras vantagens, especialmente na maximização do uso de dados disponíveis de diferentes fontes e em diferentes unidades, permitindo a manipulação de grandes quantidades de informação. Do ponto de vista do planeamento, o uso da modelação e dos SIG na avaliação dos riscos de saúde, pode reduzir o tempo de processamento da informação e fornece observações a diferentes escalas geográficas: desde a micro escala (secções da cidade) a escalas macro. Também ajuda a visualizar a ligação entre a qualidade do ar e a saúde o que e útil na discussão de diferentes opções de desenvolvimento.

Contudo, algumas melhorias podem ainda ser introduzidas no sentido de facilitar e potenciar ainda mais a integração. Um programa de integração melhorada dos dados irá facilitar a aplicação de modelos integrados na elaboração de políticas. Nesse sentido, os dados sobre a mobilidade, a monitorização e medição ambiental devem ser normalizados e legalizados. Vários modelos de tráfego, juntamente com modelos de emissão e dispersão de partículas, devem ser testados e melhorados e deve ser dada mais atenção à sua incerteza e sensibilidade.

Palavras-chave: Avaliação de Impacto na Saúde, SIG, modelação benefícios para a saúde, poluentes atmosféricos, PM10, transporte rodoviário urbano, Hai Phong, Hanói, Vietname.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AQS	Air Quality Standard
CEMM	Research Centre for Environmental Monitoring and Modeling
COPD	Chronic obstructive pulmonary diseases
DALYs	Disability-adjusted life years
DoH	Department of Health
EIA	Environmental Impact Assessment
GDP	Gross domestic product
GIS	Geographic information system
GTZ	German Organisation for Technical Cooperation
HCMC	Ho Chi Minh city
HIA	Health Impact Assessment
HSD	Highly sleep disturbance
HT	Hypertension
IHD	Ischaemic heart disease
IMER	Institute of Marine Environment and Resources
ISC3	Industrial Source Complex model
MDG	Millenium Development Goals
MoH	Ministry of Health

MONRE	Ministry of Natural Resources and Environment
NEERI	Indian National Environmental Engineering Research Institute
NEHAP	National Environmental Health Action Plan
NGO	Non-governmental organisation
NOAEL	No observed adverse effect level
PAHs	Polycyclic aromatic hydrocarbons
PM	Particulate matter
RR	Relative risk
SA	Severe annoyance
SEA	Strategic Environmental Assessment
TSP	Total Suspended Particles
USEPA	United States’ Environmental Protection Agency
UTP	Urban transportation planning
VLIR	Flemish Interuniversity Council
VOC	Volatile organic compounds
WB	World Bank
WHO	World Health Organisation

CHAPTER 1. INTRODUCTION

1.1. Literature review

1.1.1. Urbanisation and urban mobility

World urban areas have been on a non-stop rise since the industrial evolution. They are characterised by a large and dense population with high diversity, and in particular a high proportion of migrants. Urban areas economically rely on non-agricultural activities, such as industry and services, high-tech and information economies. Another dominant character is their concentration: examples include roads, buildings, infrastructure and other constructions. And finally, cities host concentrated administrative units as well as formalities.

Urbanisation arguably increases efficiency, where services can be provided at lower cost to a wider public. This applies to water, food and energy distribution, waste management, public transport, health care, fire service, security control, and administrative services, etc. Over half of the world population lives now in urban area and by 2050, this figure will be 70% (WHO 2012).

The fast urbanisation process during recent decades brought socio-environmental problems and challenges worldwide. Urban areas, especially in developing countries, are poorly managed. This results in a situation where over 50% of the world population faces major environmental, social, governance and health issues. Concentration and intensification fills-up open spaces in cities, eliminates green areas and reduces quality of life of its residents. Meanwhile the extensification process (or urban “crawl”) annexed the surrounding rural areas, where food and supplies are produced. The urbanization process also changes social functions that lead to dividing social classes, the reduction of public spaces, poor perceived safety, the increase of urban poverty and deprivation. Migration rates are often very high in urban areas, where people flog in from rural sites to find jobs and a better-serviced life.

On one hand urban mobility is a key element for the development of the city but on the other hand it has enormous environmental and health impacts. Urban areas are often transport hubs, with urban mobility at the centre connecting services and amenities a city provides. Therefore, efficiency in urban mobility has always been at the central focus whenever urban development is discussed. Transport of people and freight is essential in modern societies. It provides mobility, allows trade, is an access gate to jobs, markets, education, leisure, and services. It is an essential activity which links sectors and creates networks on which society progresses. Commuting is probably the single most important element of temporary mobility in most cities because of its volume, temporal peaking, regularity and the distances involved. Commuting is necessary for work or study purposes and often accounts for most of the personal transport in the city. However, on the environmental front, pollution, congestion, noise, and resource depletion became dominant characteristics of urban areas. These bring about also environmental health issue such as higher level of respiratory and cardiovascular diseases in urban areas.

In Southeast Asia, the urban population increases since 1950 at uneven rates. Brunei, Malaysia and Indonesia face the sharpest urban population rise, with more than 50% of their total population livings in cities in 2010. In the same year, Vietnam has around 30% of its population living in urban areas (Figure 1).

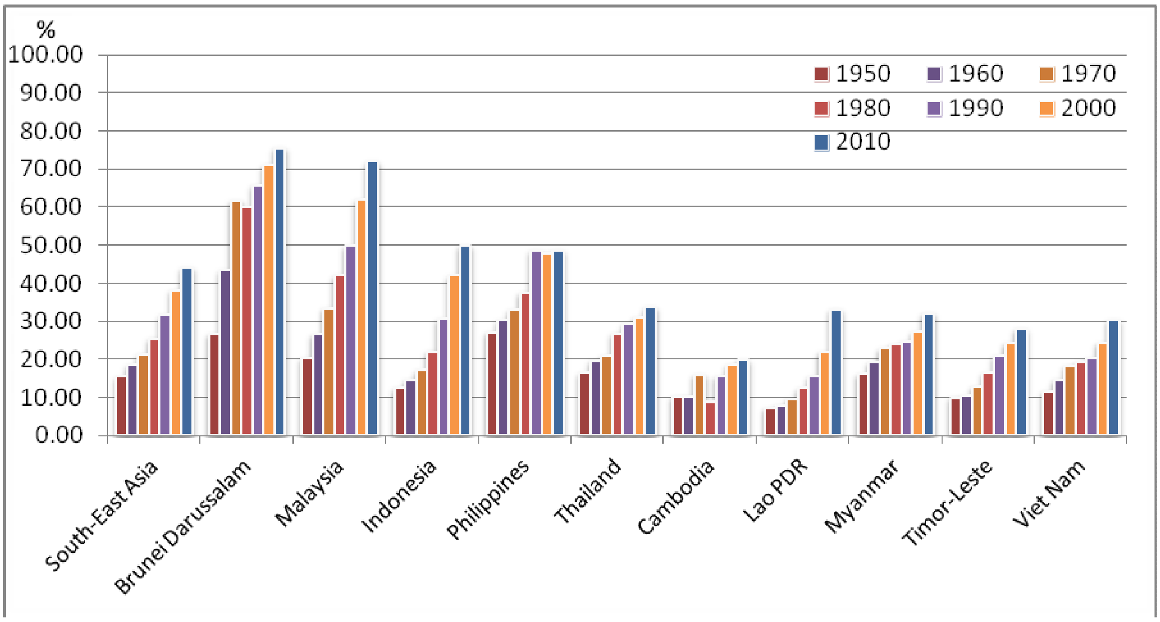

Figure 1. Proportion of the urban population in South East Asia, period 1950-2010 (United Nations Department of Economic and Social Affairs/Population Division 2012)

The United Nations Department of Economic and Social Affairs/Population Division (2012) listed the 125 most populated urban areas worldwide in 2010. Three South East Asian cities landed in the top 20. Ho Chi Minh City of Vietnam is the third most populated urban area in South East Asia, with the reported density of 9450 people/km^2, only behind Manila (the Philippines) and Jakarta (Indonesia) (United Nations Department of Economic and Social Affairs/Population Division 2012).

The GDP of the countries in South East Asia increases steadily during the past decades. Brunei Darussalam has the highest GDP among them. In terms of relative GDP per capita - measured using purchasing power - Malaysia has the highest figure in 2010 (Figure 2 and Figure 3) (United Nations Department of Economic and Social Affairs/Population Division 2012).

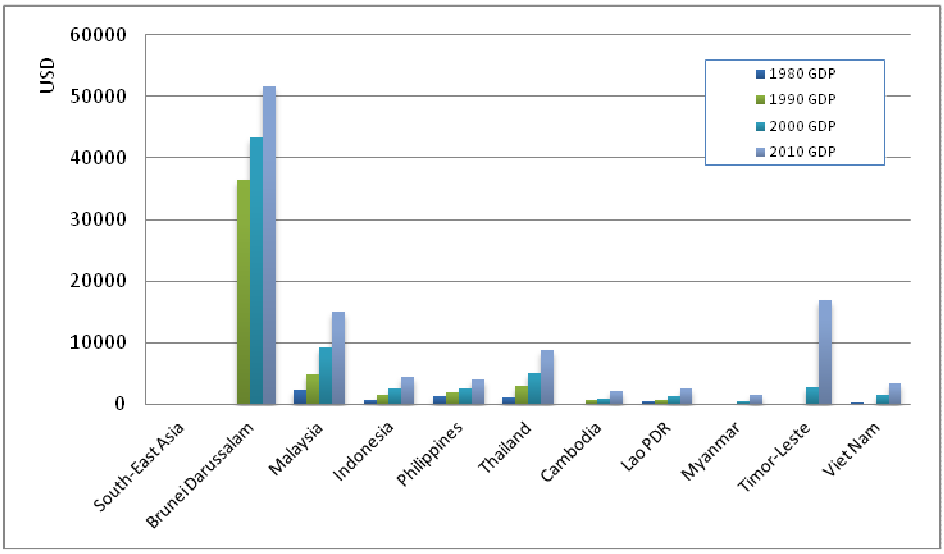

Figure 2. Evolution of average annual GDP per capita in purchasing power in South East Asia - period 1980-2010 (United Nations Department of Economic and Social Affairs/Population Division 2012)

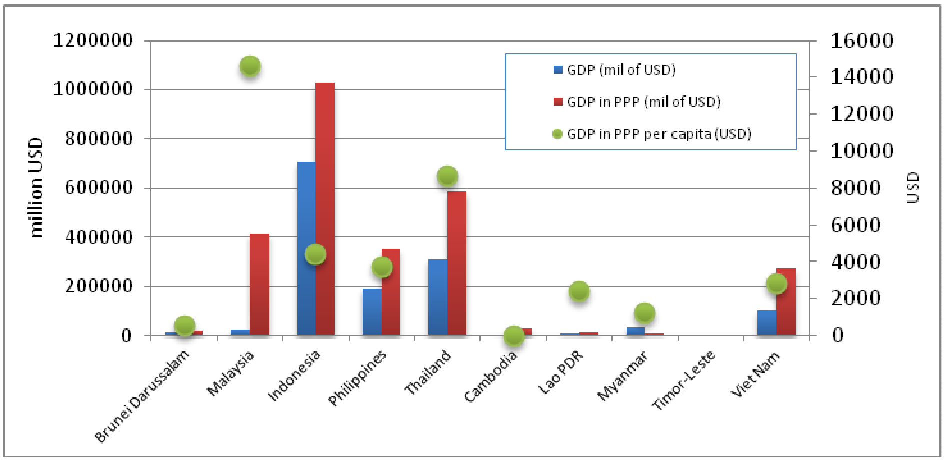

Figure 3. GDP in absolute figures, in term of purchasing power and per capita for 2010 in South East Asia (United Nations Department of Economic and Social Affairs/Population Division 2012)

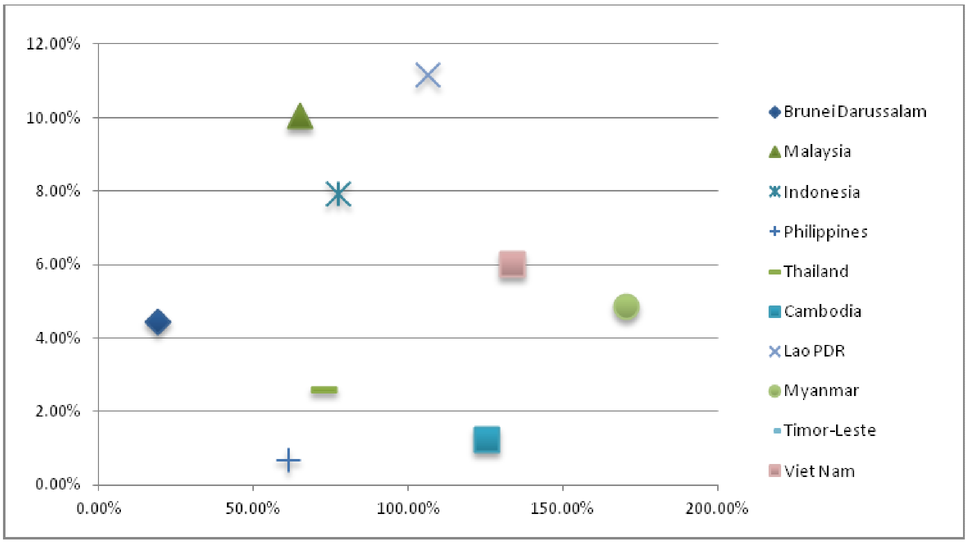

Figure 4. GDP growth rate (in purchasing power) vs. urbanisation rate during the period 2000-2010

Figure 4 shows the relation between the growth rates of GDP (in PPP) and urbanisation. Myanmar has the fastest GDP growth while Lao has the fastest urbanisation rate. Vietnam experienced a fast economic growth but the urbanisation rate slowed down between 2000 and 2010.

In Vietnam, the cities are administrative units[1]. As a rule, they include peri-urban territory, i.e. rural areas. In 1989, three quarters of Ho Chi Minh City was urban, while only a third of Hanoi and Hai Phong were urban centres (Table 1). According to the 2009 Census, the urban proportion of the population in Ha Noi decreased due to the expanded geographic area, when the former Ha Tay province (with mostly rural districts), 4 rural communes of Hoa Binh province and 1 rural district of Vinh Phuc were added to the Hanoi metropolitan area. Hai Phong experienced similar increase of its urban population. The provinces Quang Ninh, Ba Ria-Vung tau, Hai Phong and Da Nang recorded net losses of population in their countrysides but net gains in the urban areas. The Dong Nai, Ha Noi, and Binh Duong provinces dealt with high numbers of migrants coming to both rural and urban areas.

Table 1. Urban share (%) of the five most important cities in Vietnam
(General Statistics Office 2011)

Urban centre	**1989**	**1999**	**2009**
Ha Noi	35.7	57.6	40.8
Hai Phong	31.1	34.0	46.1
Da Nang	30.1	78.6	86.9
Ho Chi Minh City	73.6	83.5	83.2
Can Tho	18.0	21.3	65.8

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[1] Vietnam has 3 administrative levels: Provinces, districts, and communes. There are two types of province: cities that are centrally-governed (*Thành phố trực thuộc trung ương*) and provinces. In those provinces, there is a provincial city. There are two types of districts: urban districts are the subdivisions of the centrally-governed cities. Rural districts are subdivisions of both centrally-governed cities and provinces. Subdivisons of a district are communes (General Statistic Office of Vietnam 2014).

The 2009 census (General Statistics Office 2011) recorded that 6.6 million people migrated within Viet Nam during the period 2004-2009. This is a significant increase as compared to the 4.5 million internal migrants identified in the 1999 census. Data from the Vietnamese National census in 2009 also shows that among the more than 78 million people aged over 5 in 2009, 1.6 million people (2.1%) were intra-district migrants, 1.7 million people were inter-district migrants (2.2%), 3.4 million people (4.3%) were inter-provincial migrants, and a small proportion of only 0.1% (or 40 990 people) were immigrants who crossed national borders. As compared to 1999, inter-provincial migration is still the most frequent type of migration. Also, around a million more people migrated to another province in 2009 than in 1999 (General Statistics Office 2011). The majority of the migrants are young and the number of women is increasing. A majority of the migrants move alone, either because they are not married or because their family stays in their home community. Economic reasons are the most common driver of migration (Marx and Fleischer 2010).

However, it is important to note that the census is an official survey, which does not take into account the common practice of non-registered migration. Many people move to another district/province to work but still keep their original home address without reporting to the arrival commune. This applies especially to people working in private jobs in big cities such as housemaids, shop assistants, and manual labours. Workers in large industrial zones are often controlled more rigorously and consequently their registration as migrants are more accurate and reliable (General Statistics Office and United Nations Population Fund 2004).

The data from the 2009 census (General Statistics Office 2011) indicates that provinces with a higher urban share of the population also show a higher migrant share of the population. Ho Chi Minh City and Da Nang were provinces with exceptionally high urban shares (i.e. over 80% of the population) and thus high migrant shares. The former Hanoi (before merging with Ha Tay province in 2008) also fits in this picture. Contemporary Ha Noi and Can tho – two other central city-provinces amongst the five of those in Vietnam – were also located on the upper right quadrant of Figure 5 (General Statistics Office 2011) indicating that they both had high migrant and high urban shares of their population. In Hai Phong, the last of the five central city-provinces in Vietnam, the urban area attracts migrants from both its surrounding rural sites and from remote areas. The net migration differences (between in-migration and out-migration) are high in Hai Phong, illustrating its attraction as an important urban centre in Northern Vietnam.

Nearly half of the migrants surveyed in 2004 in Vietnam stated that they faced difficulties after arrival and experienced improper housing, a lack of access to basic utilities such as water and electricity, and insufficient access to jobs and health services, especially insured health care. The survey also revealed that around 40% of migrant experienced a decline in housing quality after moving. Almost 90% of the migrants live in rented accommodation, often in overcrowded migrant lodgings. Migrants live likely in semi-permanent houses and many depend on public ground water and toilets (General Statistics Office and United Nations Population Fund 2004).

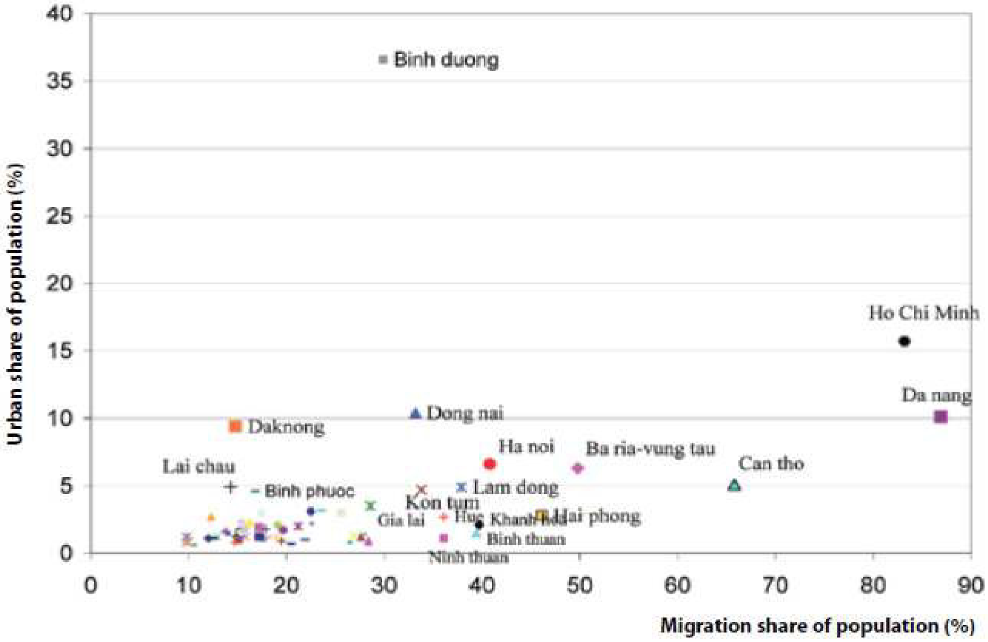

Figure 5. Migration and urban share of the population by province in 2009 (General Statistics Office 2011)

1.1.2. Environmental and health effects of road mobility in urban areas

While cities concentrate opportunities, jobs, and services, they are also hot spots of environmental and health hazards and risks. Road mobility is one of the most importance causes for environmental problems in urban area. The impact of transport on the environment is related to climate change, and degraded environmental quality (air, water, soil), and land use (Harrison, 2001; Black, 2003; Rodrigue *et al.,* 2006). Transport is a major source of ground air pollution. In northern Europe, transport contributes nearly 100% of CO, 70% of NOx, and 40% of PM_{10} of the immission values (WHO 2000). The traffic-related fraction of PM_{10} amounts to 43% in Austria, 56% in France, and 53% in Switzerland (Kunzli et al. 2000). Motor vehicles are the largest source of PM_{10} emissions in most Asian cities (Faiz and Sturm 2000). Studies in New Delhi (India), Bangkok (Thailand), Beijing (China), Hong Kong, Manila (Philippines) and Jakarta (Indonesia) show a high contribution of vehicles to the concentration of particulate matter, ranging from 40% to 80% (Bruce, Perez-padilla, and Albalak 2000; Bruce, Perez-Padilla, and Albalak 2002; Syahril, Resosudarmo, and Tomo 2002; WHO 2003; Kan and Chen 2004; Cheng et al. 2007; Sagar et al. 2007; Walsh 2002).

Motorcycles are today the prevailing way of transport in particular in fast growing cities. In 2006, motorcycles served 65% of the transport needs in Hanoi and 80% in HCMC, respectively, while cars made up 4% (Hanoi) and 6% (HCMC). In 2009, about 27.2 million motorbikes and 1.09 million automobiles were registered in Vietnam. Forecasts by the Industry Policies and Strategies Research Institute under Ministry of Industry report that there will be 31 million motorbikes in circulation by 2015 and 35 million in 2020.

Vehicle density (per 1,000 people) is the second highest in Vietnam of the developing Asian countries. The average annual growth stands at 15.1%. This is attributed to the rising incomes, which are associated with higher levels of vehicles ownership and usage (Timilsina and Shrestha 2009). The steady increase in motorisation leads to increased fuel consumption. The average annual growth rate of fuel consumption during the period 2002-2010 in Vietnam is 13.1%.

In a study composing 6 Asian countries on PM emissions, Vietnam ranks the last (Clean Air Asia 2012)[2] with a total of 11.6 thousand tons of PM emissions due to road transport. Vietnam also showed the steadiest growth in PM emissions during the period 2005-2010 with an average annual growth rate of 8.6%. Two wheelers

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[2] Due to the lack of data, PM emissions were studied only for 6 countries: India, Indonesia, Philippines, PR China, Thailand and Vietnam (Clean Air Asia 2012).

contribute around 46% of the total road transport CO_2 emissions in 2010 in Vietnam, the highest figure in developing Asia. Freight transport accounts for around 32% of the total, while buses and passenger cars account for the remaining 22%. As compared to the other developing Asian countries, Vietnam is an exception as in most others, light and heavy commercial vehicles account for most of the emissions (Clean Air Asia 2012). According to the estimates of Clean Air Asia (2012), freight vehicles account for 57% of the total road transport emissions in PR China and 54% overall in Asia.

Figure 6 shows the trends of PM_{10} pollution in the 4 largest cities in Vietnam (Da Nang, Ha Noi, Hai Phong and Ho Chi Minh City). The general trends decline, except for a slight rise in Da Nang. However, in all three cities where PM_{10} decreases, the annual average is still above the Vietnamese Air Quality Standard. Da Nang is the only city of the four which still meets the standard despite a slight increase in its PM_{10} in 2009. All four cities have higher than the 20μg/m^3 guideline of WHO.

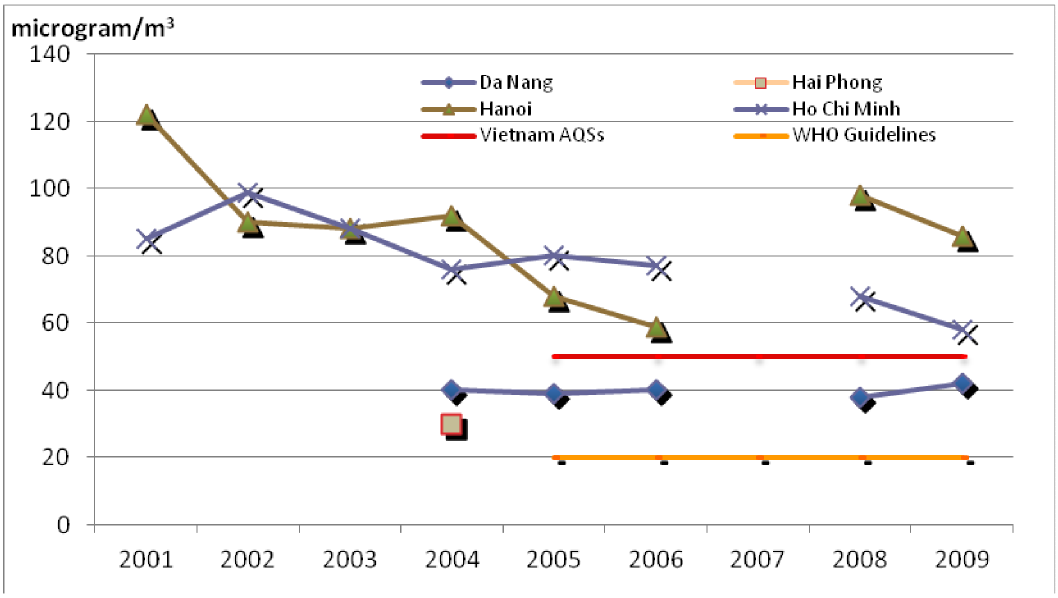

Figure 6. Annual average concentration of PM_{10} in major cities in Vietnam for the period 2001-2009

Note: Both WHO Guidelines and Vietnam Air Quality Standard (AQS) did not have values for PM_{10} *prior to 2005. Earlier, Vietnam AQS used the guideline for total suspended solids.*

As for dust, the annual average concentration of total suspended particles (TSP) in the air of the main cities in Vietnam is much higher than the standard during the period 2005-2008. When considering only the effects of road transport, the concentrations of TSP along some main roads exceed 4 times the standard (Figure 7).

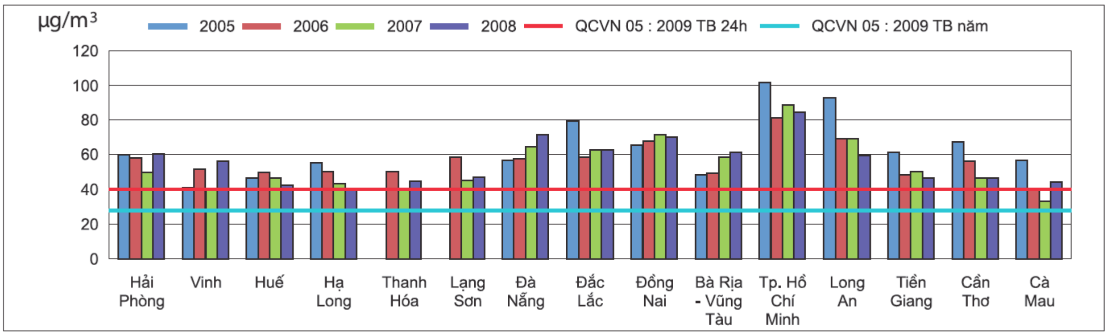

Figure 7. Trends TSP concentrations in selected urban areas in Vietnam for the period 2005-2008 (Bộ Tài Nguyên và Môi trường Việt Nam 2011)

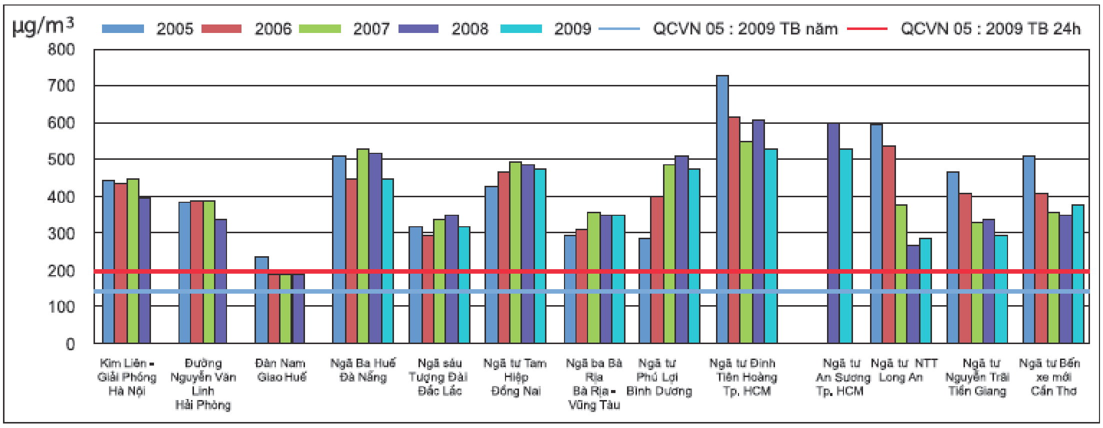

Figure 8. Trends of the TSP concentrations along selected urban roads in Vietnam for the period 2005-2009 (Bộ Tài Nguyên và Môi trường Việt Nam 2011)

The health impacts of air pollution have been studied in Europe and the United States of America since the 1930s, when the booming of industrial activities resulted in the first documented environmental crises. During the period 1930 – 1970, many studies on air pollution reported health effects. Well known examples include the pollution episodes in the Meuse Valley, Belgium in 1930 (Nemery, Hoet, and Nemmar 2001), in Donora, Pennsylvania, USA in 1948 (Ciocco and Thompson 1961), and the London smog episode in 1952 (Logan 1953; Great Britain Ministry of Health 1953). Epidemiological studies performed in the late 1980s and the 1990s confirmed the effects of air pollution on health (Schwartz and Dockery 1992a; Schwartz and Dockery

1992b; Xu et al. 1994; K Katsouyanni et al. 1997; Samet et al. 2000; Burnett et al. 1998; Michelozzi et al. 1998).

Studies by the World Bank, WHO, and the Chinese Academy for Environmental Planning on the effects of air pollution on health concluded that between 350,000 and 500,000 people die prematurely each year as a result of outdoor air pollution in China (Chen et al. 2013). However, this figures score below earlier estimate, which indicated that airborne particles smaller 2.5 microns in diameter ($PM_{2.5}$) might cause 1.2 million premature deaths in China in 2010 alone (WHO 2014).

Air pollution is known causing cardiovascular diseases, reduced lung function, cancer, respiratory problems, and effects on mental health. Noise and sedentary lifestyle are associated with indirect health effects as sleep disturbance and diabetes. The top 20 causes of mortality (MDG regions) for South Eastern Asia using DALYs show changes in the main causes between 2000 and 2011. Road injury jumped from 7th place in 2000 to 5th place in 2011, accounting for 3.7% of the total DALYs in 2011 as compared to 3.1% in 2000. Chronic obstructive pulmonary diseases (COPD) remain in the 10th place while lower respiratory infections move from the 1st place to the 3rd one. People in South East Asia are more prone to mortality due to road injury than the world average. However, forecasts show that road injury will become less prominent as a leading cause of mortality in South East Asia during the years to come. On the other hand, lower respiratory infections, which are related closely to air quality, will be responsible for more DALYs in the future (6.5% in 2015 and 6.0% in 2030) (WHO 2014).

Health effects of traffic-related air pollution are related to both individual substances (e.g. CO, SO_2, O_3, etc.) and to mixtures (diesel exhaust). Each substance or mixture has its own characteristics and may affect human health differently. Understanding the mechanism how and the extent to which a pollutant affects human health is important in assessing risks. In addition, traffic noise may also have adverse effects and is also considered as a pollutant in this study.

Motor vehicle exhaust is the most important source for increased **carbon monoxide** levels in the ambient air. Carbon monoxide binds to haemoglobin that produces carboxyhaemoglobin which impairs the oxygen carrying capacity of blood. This will result among others cardiovascular (i.e., aggravation of angina symptoms during exercise), acute pulmonary, cerebrovascular and behavioural effects, and developmental toxicity. Once the carboxyhaemoglobin level in the blood exceeds 2% this might result in coma, eventually followed by death.

Oxides of nitrogen (NO_x) (primarily nitric oxide (NO) and nitrogen dioxide (NO_2)) are gases formed by the oxidation of nitrogen in the air at high combustion temperatures, and therefore contributed by combustion engines (vehicles, ships, etc.) and other incineration processes. Nitric oxide is oxidised to NO_2 in the ambient air. It has morbidity and mortality effects, especially in susceptible groups (young children, people with asthma, chronic bronchitis and related conditions) (Morris and Naumova 1998). NO_2 has direct effects on the lung, leading to an inflammatory reaction on the surface of the lung tissue (Streeton 1997). Increased lung cancer incidence has been reported in a large case-control study (Nyberg et al. 2000), but NO_2 was primarily used as an indicator of air pollution exposure from vehicle emissions, and so other air pollutants from vehicles may have caused cancers.

Human controlled exposure studies allowed defining no observed adverse effect level (NOAEL) concentrations: the recommended short-term guidance value for a one-hour average NO_2 daily maximum concentration is 200 $\mu g/m^3$ (0.11 ppm). The recommended long-term guidance value, based on epidemiological studies of increased risk of respiratory illness in children, is 40 $\mu g/m^3$ (0.023 ppm) annual average (WHO 2006a).

Ground-level ozone is a secondary air pollutant formed by reactions of nitrogen oxides and volatile organic compounds mediated by sunlight. These primary emissions arise mainly from motor vehicles. Ozone is a photochemical oxidant (commonly called photochemical smog). Urban areas tend to have high levels of ozone pollution during sunny periods under stable weather conditions.

The pollution characterised by ozone impairs the respiratory tract, including: chest pain, lung irritation that can cause inflammation; wheezing, coughing, pain when taking a deep breath and breathing difficulties during exercise or outdoor activities; permanent lung damage to those with repeated exposure to ozone pollution; and aggravated asthma, reduced lung capacity, and increased susceptibility to respiratory illnesses like pneumonia and bronchitis (Woodward et al. 1995).

Its toxicity occurs in a continuum in which higher concentrations, longer exposure, and more activity during exposure causes more adverse effects. There is no indication of a threshold concentration for health effects (Streeton 1997). Substantial acute effects occur during exercise with one hour exposure to ozone concentrations of 500 µg/m^3 or higher. WHO (2006) suggests the air quality guideline of 100 µg/m^3 8-hour mean of ozone. Time-series studies indicate an increase in daily mortality in the range of 0.3–0.5% for every 10 µg/m^3 increment in 8-hour ozone concentrations above an estimated baseline level of 70 µg/m^3 (WHO 2006a).

Sulphur oxides (primarily SO_2 and limited quantities of sulphur trioxide (SO_3)) are gases formed by the oxidation of sulphur contaminants in fuel during combustion. The main traffic source of SO_2 is diesel combustion, e.g. from trucks and ships. SO_2 is a potent respiratory irritant, and is associated with increased hospital admissions for respiratory and cardiovascular disease (Bascom et al. 1996), as well as mortality (K Katsouyanni et al. 1997). Asthmatics are a particularly susceptible group. A threshold concentration for adverse effects in asthmatics after short-term exposures to SO_2 (570 µg/m^3 during 15 minutes) has been described (Streeton 1997). WHO (2005) recommends a 24-hour guideline of 20 µg/m^3.

Volatile organic compounds (VOCs) are hydrocarbons include benzene, toluene, xylene, 1,3-butadiene, polycyclic aromatic hydrocarbons (PAHs), formaldehyde and acetaldehyde. Motor vehicles are the most important sources of VOCs in urban areas. Special attention should be given to benzene, a carcinogen causing leukaemia in humans. The potential health impacts of VOCs include carcinogenic and non-carcinogenic effects (e.g. damage to the central nervous system and skin irritation) (Fisher et al. 2002). Health effect data and guidelines/standards for hazardous air pollutants have been reported (Chiodo and Rolfe 2000), and include recommended air quality guidelines for benzene of 3.6 µg/m^3 by 2010 (when the benzene content of petrol is reduced) (Fisher et al. 2002). Estimates generally assume a no-threshold and linear dose-effect relationship at low-doses. The Air Quality Guidelines for Europe (WHO 2000), indicate an excess lifetime risk of cancer (leukaemia) at an air concentration of 1 µg/m^3 of 6×10^{-6}.

"**Particulate matter**", also known as particulate pollution or PM, is a complex and varied mixture of small particles and liquid droplets. Particle pollution is made up of acids (such as nitrates and sulphates), organic chemicals, metals, and soil or dust particles. The size of the particles is directly linked to the health problems they cause. The United States' Environmental Protection Agency (USEPA) is concerned about particles of 10 micrometres in diameter or smaller, because these pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects. Based on this criterion, there are two categories of PM:

"Inhalable coarse particles," such as those found near roads and in dusty (e.g. cement) industrial plants, are larger than 2.5 micrometres and smaller than 10 micrometres in diameter. "Fine particles", such as those found in smoke and haze, are 2.5 micrometres in diameter or smaller. These particles can be directly emitted from sources such as forest fires, or can be formed when gases that are emitted from power plants, industries and automobiles react in the air.

Particles, in particular PM_{10}, have been the subject of many epidemiological studies and, more recently, many reviews of these studies. The studies, in various parts of the world with different climates, socio-economic status, and pollution levels, consistently showed that 24-hour average concentrations of PM_{10} are related with a variety of health impacts. Among other they cause increased respiratory symptoms, such as irritation of the airways, coughing, or difficulty breathing, for example; decreased lung function; aggravated asthma; chronic bronchitis; irregular heart rhythm; non-fatal heart attacks; and premature death in people with heart or lung disease (Dockery et al. 1993; C A Pope, Dockery, and Schwartz 1995; Krewski et al. 2005; Zanobetti et al. 2002; Fisher et al. 2007; Anderson et al. 2004). These relationships are causal.

People with heart or lung diseases, children and older adults are most likely to be affected by exposure to particles. However, even in healthy people, temporary symptoms arise following exposure to elevated levels of particle pollution. Fisher et al. (2007) suggest the threshold of the PM_{10} exposure level for mortality effect is set at 7.5 ($\mu g/m^3$). For morbidity, a no-threshold is suggested by the same author, arguing that each increase in PM_{10} will increase the risk of contracting a health complication, notable COPD, respiratory hospitalisation or a simple restricted-activity day.

Transportation also causes **noise**. Health impacts of noise include among others annoyance, impaired communication and increased aggression. Other adverse effects are reduced school performance, disturbed sleep and moodiness, as well as cardiovascular effects and hearing impairment. '***Annoyance'*** can be defined as 'any feeling of resentment, displeasure, discomfort and irritation, occurring when noise intrudes into someone's thoughts and moods when contemplating or interferes with an activity' (Passchier-Vermeer and Passchier 2005). The degree of annoyance increases with increasing sound levels. WHO (2000) points out that people are moderately annoyed at 50dB L_{Aeq}, while at 55dB L_A's serious annoyance occurs. These data are only applicable during the daytime. At night, the threshold for being annoyed is lower, and will be discussed as a sleep disturbance effect (*see below*). Noise can cause ***sleep disturbances*** especially when sound levels above 30dB L_{Aeq} (steady-state continuous noise) or 45dB L_{Amax} (noise events) are reached (WHO 2000). There are many ways in which sleep disturbance manifests itself. First of all, noise can affect sleeping behaviour, sleep pattern, and physiological responses. The effects can be divided into three groups: primary effects, secondary effects and long-term effects. Primary effects include "difficulties in falling asleep, awakenings, sleep stage changes and instantaneous arousal effects during sleep (temporary increase in blood pressure, heart rate, vasoconstriction, release of stress hormones in the blood, increased motility)" (Nicolopoulou-Stamati et al. 2005). Secondary or *after effects* are measured the next day and include "decrease of perceived sleep quality, increased fatigue and decrease in mood and performance". Long-term effects on well-being include 'increased medication use or chronic annoyance' (Nicolopoulou-Stamati et al. 2005). ***Ischaemic heart disease*** and ***hypertension*** are also effects associated with noise exposure. Sound levels above 65 to 70dB L_{Aeq} during the daytime offer a risk, although these effects are rather small (de Kluizenaar et al. 2007).

Transportation impacts **safety** and causes **accidents and injuries**. Traffic accidents are hazardous, not only at the moment they happened. Their long-term impacts can include posttraumatic stress from accidents, nightmares, flashbacks or uncontrollable, intrusive recollections. The accidents caused by increased road traffic became a major public health issue. For example, in Europe, accidents cause about 34,500 deaths per year in 2009 (Eurostat 2014). This number only includes deaths caused by accidents and does not include people injured in road traffic crashes, neither it includes the psychological effects of accidents. Victims of accidents often experience an increasing fear of traffic and as a result they prefer the car above walking or cycling, which results in a decrease of physical activity. In Europe, pedestrians account for around 25 to 30% of deaths and 13% of the injuries in all accidents, while cyclists account for 5 to 6% of deaths and 7 to 8% of the injuries. Over 60% of deaths and 60% of the injuries are people driving a car (WHO 2000). The world's fatality rate is 19 deaths per 100,000 people, with much lower rates in high-income countries. For Vietnam, a total of 20,774 incidents were reported in 2003, leading to 12,864 deaths, 20,704 injuries and millions of USD in costs (WHO 2004).

In Vietnam, the number of road traffic fatalities increased from 4,907 in 1994 to 11,534 in 2005. The road traffic fatality rate (number of deaths per 100,000 population) is 26.7. Motorcycles account for the highest proportion (59%) of road traffic collisions, followed by bicycles/tricycles (24%), pedestrians (11%) and motor vehicles (4%) (Ministry of Health of Social Republic of Vietnam 2006). In 2003 alone, a total of 20,774 incidents were reported, leading to 12,864 deaths, 20,704 injuries and millions of USD in costs. Traffic accidents have increased steadily over the period 2000-2007. It is important to note that for most of the deathly traffic accident cases, there is no hospital record. Also, minor cases are also not properly recorded. And in both situations, not all traffic accidents are recorded. Many minor accidents are not reported, especially when no serious injuries occurred. Also, many people with minor injuries do not seek help from hospitals. As the number of traffic accidents was accounted differently by different agencies and there is no cross-reference between them, the accurate number of traffic accidents in Vietnam is difficult to estimate.

Accidents also have mental consequences. Posttraumatic stress involves symptoms as re-experiencing the trauma through nightmares, flashbacks or uncontrollable, intrusive recollections. '14% of survivors have diagnosable posttraumatic stress disorder and 25% have psychiatric problems one year after an accident, and one third have clinically significant symptoms at follow-up 18 months after an accident' (WHO 2000). Also the development of avoidance techniques – e.g. keeping away from situations that trigger recollections of the event – and a creation of excessive arousal could result in sleep difficulties, poor concentration and disturbed memory (WHO 2000).

Transportation also has **negative impacts on mental health and wellbeing** aside from mental problems caused by accidents. Air pollution of leaded petrol causes cognitive development impairment in children, increased aggression and stress, the reduction of social life, especially among elderly, a decrease of physical activity among children which contributes to sedentarism, that in turn results in other health impacts such as weight gain and physical weakness. Lead has neurotoxic impacts on human beings, but it is only recently found that those effects occur at much lower exposure levels than previously presumed. Scholars also concluded that children are particularly vulnerable since they have greater intakes of lead than adults and they also absorb and retain lead easier (WHO 2000). Even the cognitive development of the foetus experiences adverse effects of lead (Moshammer, Hutter, and Schmidt 2005). Today, most countries switched to unleaded petrol, although there are still communities where leaded petrol has not yet been phased out. Leaded petrol was phased out in Vietnam in 2001 and the concentration of lead in the air declined systematically since then.

People exposed to high noise levels get annoyed and as a result they become stressed. Children experience difficulties with school performance. They are less motivated, have concentration problems, and show a poorer reading ability. Transport also shows direct influences on mental health and wellbeing. There are still other aspects of transport that cause stress, for example traffic congestions make people frustrated in particular when they are in a hurry. The outcome is increased blood pressure, aggressive behaviour and increased likelihood of crashes (WHO 2000).

Automobile transport is also associated with '**perceived safety**'. Since people are afraid of accidents, they are more inclined to use the car instead of a bicycle, even for short distances (Moshammer, Hutter, and Schmidt 2005). This trend offers less opportunity for social interaction. Nevertheless, this interaction is a psychological need, deficiency leads to social isolation. Lack of social support increases mortality from coronary heart disease by up to four times (WHO 2000).

The psychological effect of the “perceived safety’ also leads to using less vulnerable modes of transport such as walking and cycling. One of the consequences is the people, especially children, are less physically active. Long period of inactivity leads to *sedentarism*. The effects of sedentarism include: a decrease of cardio-respiratory fitness, a decrease of stress tolerance, a decrease of independence in old age, constraints on child development (fewer children walk or cycle to school), an increase of neuro-degenerative diseases and a decreased control of body weight that can lead to obesity (Nicolopoulou-Stamati et al. 2005). Obesity is associated with cancer, heart diseases, depressions and asthma in the long run. Thirty minutes of walking or cycling a day is enough to reduce the risk of developing cardiovascular diseases, diabetes and hypertension. Furthermore, it helps to control blood lipids and body weight (WHO 2000).

1.1.3. Health Impact Assessment

1.1.3.1. State of the art

Health Impact Assessment (HIA) is one of the ways to assess impacts of pollution on human health. Different methodological approaches to HIA exist both in in the literature and in practitioners’ reports worldwide. The first notable variations derive from the different “health definitions”: they vary between health defined in a broad way of “health and well-being” or in a narrower context of the avoidable illness and death. The broad definition of health has its root mainly in sociology and rarely quantifies risk. Instead, it places a focus on the popular concern on health inequalities. The narrower definition of health has its roots in epidemiology and toxicology and emphasises that health is measurable and the associated risks can be quantified (JR Kemm 2000). Both definitions offer a scope which can be addressed by a HIA context. Depending on the health definition used, the process of HIA varies. However both definitions are not exclusive. Health inequalities can be assessed examining differences within the population, especially among groups which are marginalized or disadvantaged (Harris-Roxas et al. 2012; Veerman, Barendregt, and Mackenbach 2005).

The standard HIA procedure includes four steps: Risk characterization – Dose-Response Assessment – Exposure Assessment – Risk/Impact Assessment. Risk characterisation is the process of identifying the hazards linked to an air pollutant. The main aim is documenting whether an agent causes adverse effects on human health. Risk characterisation is based on a literature review. Health impacts related to transportation link health outcomes with transport activities. Air pollutants are associated with a wide range of health problems including acute pulmonary effects, cerebrovascular and behavioural effects, and respiratory and cardiovascular diseases. Dose-response assessment establishes a quantitative relationship between the dose of a pollutant that an individual exposed to (exposure) and the experienced health. Dose-response functions are established using epidemiological data (Kunzli et al. 2000; S Medina et al. 2005; Fisher et al. 2002; Fisher et al. 2007). Exposure assessment is the process which quantifies the magnitude, frequency and duration expose to a particular pollutant. Both direct and indirect exposure matters. Direct exposure quantifies the pollutant concentrations reaching an individual. The concentrations of the pollutant are directly measured on or in body fluids of the person (at the point of contact, biological monitoring, or biomarkers). The three methods provide data on different aspects of exposure. The point of contact approach indicates the total concentration reaching the subject, while the other two show the amount of the pollutant present in the body. The indirect approach measures the pollutant concentrations in various locations or during specific human activities to predict the exposure in a population.

The direct approach measures individual exposure, while the indirect approach estimates exposure of a population. Each approach has its advantages and limitations. While the direct measurement is invasive, costly and time consuming (requiring that the measured subject keeps a record of exposure during all activities and at all locations), it provides more accurate individual exposure data. The indirect approach has the advantage of minimal invasiveness and is associated with lower costs than the direct approach. The results do not reflect actual exposures, this results in inaccuracies in the assumptions made during the study, the time-activity data, or the measured pollutant concentrations.

HIA can be done quantitatively or qualitatively. A combination of these two can also be used. Quantitative approaches quantify health outcomes as changes in health determinants due to policy interventions or changes in the exposure to pollutants. This approach estimates changes in environmental factors and predicts possible health outcomes based on risk assessment. The quantitative approach mainly uses epidemiological and toxicological risk assessment data to determine health outcomes, and is therefore widely used to calculate health risks in relation to exposure to pollutants in the environment. Health risks related to traffic or water pollution are some of the examples (Mindell et al. 2001; Veerman, Barendregt, and Mackenbach 2005; O'Connell and Hurley 2009).

The qualitative approach on the other hand aims to identify health concerns using a descriptive method. Risk assessment is defined as one of the risk analysis components required to quantify, or qualify, a specific level of risk, using four inter-related steps: estimating the likelihood of a hazard; estimating the likelihood of susceptible humans or animals being exposed to the hazard; the description of the results of the release and exposure to the hazard for humans and animals (health and/or economic consequences); and the estimation of the resulting risk by combining the results of the preceding three steps (Dufour et al. 2011). A qualitative approach can be useful when a group of experts is available to discuss the steps arriving at the risk estimation. The qualitative approach is particularly useful in risk characterisation when quantified epidemiological and toxicological risk figures lack. The method often requires substantial amounts of data, deals with the finding that many risks are not fully quantifiable, and with uncertainty (Mindell et al. 2001). Further developments in the area of qualitative HIA methods necessitate research to quantify the socio-economic and behavioural effects 'user friendly simulation models' the use of direct measures of public health, expert opinions and scenario building'; and empirical research on the validity and reliability of the methods (Veerman, Barendregt, and Mackenbach 2005). Often, a combination of both qualitative and quantitative approaches is used to determine the health impacts of policies, programmes, plans and projects (Love et al. 2005).

From the legal point of view, both compulsory and voluntary HIA procedures exist. Compulsory HIAs are those conducted according to legal requirements. Health aspects can be regulated using laws and regulations which focus on health (such that those concerning public health or disease control) or through those regulating socio-environmental determinants which affect human health (such that those controlled by EIA/SEA regulations). Voluntary HIAs are performed independent of those requirements, especially in the cases where EIA/SEA does not integrate HIA (Harris-Roxas and Harris 2011). Although legal HIA procedures are important in ensuring that health concerns are mainstreamed and that HIAs are conducted following a prescribed process which can be controlled for legal purposes, this type of HIAs puts most emphasis on the scientific aspects identifying potential health impacts and often faces legal disputes. This entails that practitioners of legally embedded HIAs need to be accredited and the roles, responsibilities and accountabilities of proponents, regulators and practitioners are clearly defined. Comprehensive quality guidelines for conducting, reporting and assessing HIAs need to be available (Harris-Roxas and Harris 2011; Fredsgaard, Cave, and Bond 2009). The legal process can be complicated and takes a long time. On the other hand, voluntary HIAs are merely based on the voluntary willingness of HIA practitioners and will not be subjected to the [rigid] process foreseen by the law. Practitioners will decide and choose which type of HIA is most suited for the subject at hand. However, the weakness of the voluntary approach is in its quality control, especially when the results of the HIAs will be reported in a lobbying context.

In an environmental health context, HIA can also be categorized into those independent of EIA, and those formally integrated with EIA (Cole et al. 2004; Dannenberg et al. 2006; J. Kemm, Parry, and Palmer 2004). Independent HIAs provide opportunities for both quantitative and qualitative approaches, whereas integrated HIAs often favour quantitative analytic methods, potentially limiting their scope. However, both approaches call for interdisciplinary attitudes and more discussion on the environmental determinants of the health outcomes (McCaig 2005; Wright, Parry, and Mathers 2005; Noble and Bronson 2005; Gorman et al. 2003).

Depending on the type of HIA, different initiators exist. Often, when HIAs are required by law, the initiator is defined. Similar to any EIA or SEA, project promoters are often the initiators of HIA. On the contrary, when HIAs are voluntary, initiators of HIA vary. They can be health activists, NGOs promoting healthy environment, or the authority that proposes the action.

Although HIA has its roots in EIA, which is mostly project-driven, HIA can also be expanded to plans, programme and policy. This changes health from a *component* in effects of a project into a *determinant* of the policy, plans or programme (Mahoney and Durham 2002). While for a project assessment, HIA targets health as a component of many other issues, policy-linked HIA puts the whole focus on health. This is often done at two occasions. At first when health is the goal of the policy in question, and at second is when health is not the immediate goal but there is a need putting health on the agenda. Using HIA for both projects and policies has a common goal ensuring that the project or policy will not result in or mitigate the adverse health impacts on the community. Nevertheless, the approach to HIA for projects and for policies varies. It is currently unclear how communities should be involved in the HIA process in the most efficient way, either at project or at policy level.

HIAs differ also in rapidity and intensity. Both rapid HIA and comprehensive HIA require the same main procedural steps of Screening/Scoping – Assessment/Appraisal – Reporting/Recommendations/Decision-making – Evaluation/Monitoring (Lester and Temple 2004; Harris 2005; Furber et al. 2007). However, rapid HIA is often done faster using consultation with relevant experts and stakeholders, taking advantages of their knowledge and available data on the subject to assess possible health effects. Comprehensive HIA has an extended appraisal scope, where new information is generated, significant literature reviews are undertaken and comprehensive involvement of stakeholders occurs. All this results in a more complex process for which more time is required (Furber et al. 2007). In both rapid and comprehensive HIAs, qualitative or quantitative approaches can be used or the combination of both. The combination can be done using either approach for any of the steps.

1.1.3.2. Health Impact Assessment in South-East Asia region

In many countries of South-East Asia, HIA has been implemented, although with differences in approach. In most countries, including Cambodia, Lao PDR, and Malaysia, HIA is conducted on a project-by-project basis as part of Environmental Impact Assessment (EIA). If indicated, policy decision integrates health and environmental impacts. Thailand uses a public policy process on HIA both for strategic and projects EIA. HIA can be initiated both by local communities and local governments. Both in Thailand and Vietnam, HIAs are conducted ad-hoc in various cases. The assessments vary in scope and size: they range from national policies on transportation, agriculture and energy, to public health and disease control programs.

A meta-analysis of 421 peer-reviewed reports addressing the health aspects of pollution were published in 11 Asian countries since 1980 showed effects on daily mortality and hospital admissions (PAPA-SAN 2008). Among these 421 HIAs no Vietnamese study is included.

China published over 200 studies during the last 25 years (including those performed in Hong Kong and Taiwan) (PAPA-SAN 2008). Most of the reports concern metropolitan areas or industrial cities. The main health outcomes dealt with the relationship between ambient pollution and respiratory symptoms and disease, mortality and hospital admissions. Most HIAs examined the health effects of exposure to PM, NOx, and SO_2. Many studies examined the combined exposure to PM and other gaseous pollutants, other ones separated the health effects of either PM or other air pollutants. Biomarkers, birth outcomes, hospital admissions, lung cancer incidence, and school absence were studied. The prevalent methods are time-series or cross-sectional study designs. During the late 1980s, the cross-sectional study design was widely used to investigate the relationship between ambient pollution and lung cancer morbidity and the prevalence of respiratory symptoms and disease. As more routine and reliable air quality–monitoring data became available in more major cities during the early 1990s, more time-series studies were setup, investigating changes in all-cause and cause-specific morbidity and mortality in relation to changes in urban air pollution.

In other industrialised countries in East Asia such as Japan and South Korea, research focused on respiratory symptoms and disease, mortality, hospital admissions, lung cancer incidence, birth outcomes, school absence, eye disease, atopic dermatitis, and biomarkers. Most were cross-sectional and time-series studies. About two-third of the reports estimated the health effects of exposure to PM, gaseous pollutants, or both.

In Southeast Asia, health impact studies exist for Indonesia (9 reports), Malaysia (3 reports), Singapore (10 reports), and Thailand (26 reports), but no reports were identified from Bhutan, Burma, Cambodia, Nepal, Philippines, or Vietnam. The prevalent approach used in the identified reports is the evaluation of the health consequences and the economic effects of exposure to ambient pollution. Panel, cross-sectional, and time-series methods are used to study health outcomes including respiratory symptoms, respiratory disease, and mortality. Studies in Singapore assessed children's respiratory symptoms and diseases, such as asthma. In Thailand, most studies concern Bangkok and the nearby areas estimating the health effects of exposure to PM and gaseous pollutants. The majority of these studies focus on the effects of exposure to PM only.

Table 2. Number of studies in SE Asia and the Far East (Japan and South Korea) by study designs, assessed pollutants and assessed health outcomes (adapted from PAPA-SAN 2008) (Number in brackets is the number of studies)

Study designs	**Assessed pollutants**	**Assessed health outcomes**
Case–control (10) Case–crossover (20) Cohort (27) Cross sectional (168) Ecologic (23) Health impact (43) Panel (28) Time series (99)	Particulate matter and gaseous pollutants (216) Particulate matter only (49) Gaseous pollutants only (29)	Birth outcomes (23) Hospital admissions, visits, and discharges (46) Mortality (99) Respiratory disease, symptoms, and function (173)

Cross-sectional studies are the most commonly used methods to study the health effects of long-term exposure to air pollution. They study the prevalence of chronic respiratory symptoms and disease or on chronic impairment of pulmonary function (PAPA-SAN 2008). Over one third of all studies identified used this approach. The disease status and exposure to air pollution of the population at a fixed point in time are determined to calculate the effect of exposure on the prevalence of disease. The weakness of this approach is that it is often not possible to determine the temporal relationship between exposure and disease. Case–control, case–crossover and cohort studies are less frequently used in the region. They cover only 10% of the total number of published studies. These approaches are used to calculate the relative risk of disease. The relative risk of a disease or mortality that is associated with a particular exposure factor can be calculated based on the cases people developed or died from according to their exposure to air pollution. Also other confounding factors are taken into account in quantifying the risk. In *case–control studies*, the relation between air pollutant concentrations and the number of people who were free of the disease at the time that they became ill or died is studied. In *case–crossover studies*, the relation between the number of cases of particular diseases that occur in a population due to short-term exposure to air pollution is assessed. The effects of prolonged exposure to air pollution on mortality and morbidity of chronic disease can be estimated studying cases over long time (*cohort study*). These three approaches are all time- and effort consuming and require large samples.

Particulate matter is the most frequently studied air pollutant. Particulate matter can be studied as Total Suspended Particles (TSP), as PM_{10} or as $PM_{2.5}$. However, most of the studies on the health effects of particulate matter focus either on PM_{10} or TSP. Studies on $PM_{2.5}$ are scarce. Particulate matters are often studied together in combination with other gaseous pollutants as SO_2, NOx and ozone (PAPA-SAN 2008).

PM is gaining increasing importance as an indicator pollutant in health impact studies. While the effects of other pollutants cannot be dismissed, PM can be used as an indicative pollutant in assessing both health outcomes and socio-economic effects of policies or projects (Qiu et al., 2012; Quah and Boon, 2003; Sagar et al., 2007; Zhang et al., 2008, 2007). Most of economic studies on HIA in South East Asian during the period 1990-2007 used PM as the main indicator (PAPA-SAN 2008).

1.1.3.3. Health Impact Assessment in Vietnam

The health effects of economic and development activities in Vietnam are merely assessed using empirical surveys in which personal exposure to air pollution is related with health outcomes. These outcomes are obtained using health surveys (health status questionnaires, clinical assessment of criteria health outputs and hospital records) to determine the current level of impacts and to project the expected future impacts. This research strategy was used to study the health impacts of traffic in Ho Chi Minh City and Hanoi (Vo 2005; Vo and Nguyen 2007). Health impacts of other sectors (industry, constructions, etc.) were studied in similar way (Cao and Pham 2007; Chu 1996; MONRE 2008; Pham 2005; Sumi, Le, and Vu 2007).

The project Air Pollution, Poverty, and Health Effects in Ho Chi Minh City (HCMC), which was funded by Asian Development Bank (ADB) during the period 2005-2008 used three methods of assessment. A hospital-based study estimated the effect of short-term exposure to air pollution on hospital admissions for respiratory illnesses among children under five years in HCMC during the period January 2003-December 2005 (Le et al. 2012). The study used daily average exposure to PM_{10} and ozone as environmental parameters. The socioeconomic position (SEP) of the children's families was assessed based on the administrative information of the hospital and the location of their residence. A time series analysis and a case-crossover analysis were performed. The study results showed the association between the exposure to PM_{10}, ozone, nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) and hospital admissions for the young children in the HCMC. The second part was a household study. The objective was to assess the socio-economic determinants of personal exposure (poor and non-poor), and to explore whether the use of ambient monitors as an alternative for personal exposures measurements could result in the misclassification of exposure for different socio-economic status. The results indicated that the exposure of the poor and the non-poor was not significant. Finally, a policy study was conducted based on desk review and interviews to identify the gaps in the existing policies and the policy-making process and to recommend measures (local and national level) reducing the impact of air pollution on the poor. The study suggests to integrate air quality management in the relevant sector development planning at all levels (HEI Collaborative Working Group on Air Pollution; Poverty and Health in Ho Chi Minh City 2012).

Different research strategies assessing health impacts of urban air pollution exist (Cao and Pham 2007). A combination of both qualitative and quantitative studies is indicated, including epidemiological studies which combine health surveys with air quality monitoring and cross-sectional analysis. Health impacts are estimated based on dose-response functions. In this research, no indicator pollutants are suggested. Dust and other gaseous pollutants are considered together.

1.1.4. Environmental health effects of mobility in decision making

Urban air pollution contributes to approximately 800,000 deaths and 6.4 million lost life-years worldwide in 2000 and two-thirds of these losses occur in developing countries of Asia (WHO 2012). Such estimates drive relevant environmental policies. While it is clear that air pollution due to road transport, especially in urban areas, affects health of the population, the extent of these risks often less clear. Nevertheless this information is of core impotence for planners and decision-makers when deciding on the options for future development.

Health Impact Assessment (HIA) estimates and evaluates the health impacts of policies, plans, programmes and projects in a wide variety of sectors using quantitative, qualitative and participatory techniques (WHO 2012). HIA builds on the recognition that health is not only determined by the “health services” provided by the government, but is heavily influenced by various economic, social and environmental factors. Measuring health indicates to which extent a society moves towards sustainable development and allows improving the process. HIA lays out different health issues, alternatives and improvements to prevent disease. HIA should be done before the proposal is implemented to suggest indicated mitigating measures. HIA equally contributes to increased awareness of health among decision makers in different sectors. This facilitates inter-sectorial collaboration. It also facilitates community involvement in decision-making and promotes sustainable development, democracy, equity, comprehensive and scientifically-sound evidence.

In the ASEAN policy space, the concept of HIA is known, but it is not based on well developed policy or regulation. In contrast with EIA which is well embedded in laws, HIA is hardly regulated (As reported in the 2nd Workshop on "Constructing a Caring and Sharing Community: Roles of HIA" in 2012 (http://www.hiainasean.org). In all ASEAN countries, except Thailand, HIA is part of the EIA process. In Thailand, a separate HIA policy is part of the Health Promotion Act. However, in other countries such as Cambodia and Vietnam, HIA entered the national policy with the National Health Action Plan (in Vietnam) or National Committee on Health (in Cambodia). These events resulted in the formulation of guidelines and regulations on HIA (Petcharamesree 2012; Prak and Khuon 2012; Sriwongsa 2012; Anon. 2012a; Anon. 2012b; Nguyen, Danh, and Anh 2012).

In Vietnam, health issues were first dealt with in the 1993 Law on Environment Protection and in the Decree guiding the implementation of the Law, which regulated HIA as a part of EIA. However, there was no guideline on HIA and consequently HIA was not applied. Some ad-hoc assessments were performed merely on occupational health.

In 2005, an improved version of the Law on Environment Protection was published replacing the 1993 law. Decree No. 80/2006/ND-CP guides the implementation of the Law and separates HIA from EIA. The updated guidelines published in 2008 through the Circular No. 08/2006/TT-BTNMT dated 08th December, 2008 also kept HIA out of EIA. Although health issues are mentioned in the law, no documents on guiding HIA have been published.

HIA was also addressed by the Law on Prevention and Control of Infectious Diseases issued in 2007. According to this law, HIA must be done for development projects for industrial zones, cities, and health-care facilities for infectious patients. HIA is therefore limited to projects, which are at risk of spreading communicable diseases e.g. among workers in industrial zones or by hospitals dealing with infectious diseases. In this context health is interpreted in a narrow sense. Moreover HIA focuses merely on "[infectious] diseases", which are of traditional concern in the healthcare sector. Environmental health issues are not covered by the law.

The separation of HIA from EIA is merely related to issues of competence: the Ministry of Natural Resources and Environment (MONRE) is responsible for policies and regulations on environmental issues (EIA included), while the Ministry of Health (MOH) is competent for policies and regulations on health issues (HIA included). In response to these overlapping competences, a new agency was established within MOH. This Health and Environment Agency is now the focal point for HIA. It is responsible for developing regulations on HIA, developing a national Action Plan on HIA in Vietnam, and developing technical guidelines for HIA, aiming for institutionalising HIA and including HIA into the National Environmental Health Action Plans (NEHAP) by the end of 2015 (Nguyen, Danh, and Anh 2012).

Despite HIA was not legally required prior to these legal regulations, some HIAs were realised. Most of them were part of research projects on HIA or the integration of health issues in EIA/SEA. Other ones are studies commissioned by international organisations as the World Bank (WB), Asian Development Bank (ADB) or German Organisation for Technical Cooperation (GTZ). Various methods are used in these HIAs, depending on the requirements of the project or on the background of the involved researchers/experts.

1.2. Problem formulation

1.2.1. Difficulties in implementing integrated HIA in Vietnam

A literature search of Vietnamese studies on planning showed that health effects of economic and development activities were included. They merely use empirical surveys of personal exposures to air pollution and associated those with health outcomes obtained through health surveys (health status questionnaires, clinical assessment of criteria health outputs such as measuring lung functions, and hospital records). This allows determining current levels of impacts and projecting expected impacts in the future. Health impacts of transport have been studied to a limited extent in major cities in Vietnam (Ho Chi Minh City and Hanoi) using this approach (T.-Q.-T. Vo 2005). Health impacts in other sectors were addressed in a similar way (Cao and Pham 2007; Chu 1996; Anon 2007; MONRE 2008; Sumi, Le, and Vu 2007; Le et al. 2012).

The main shortcoming of this approach is that it requires a substantial empirical study, which is often very time consuming and has a variable accuracy. Also, the spatial and temporal scopes of such study are usually missing. Furthermore, it is not possible to differentiate health effects of different sources on a health outcome. Therefore, health impacts of air pollution are not routinely studied.

Using dose-response function in HIA allows a higher accuracy while one does not need to perform personal and individual monitoring of exposure and related health outcome. Studies also suggested that the use of modelling and mapping as tools to visualize expected outcomes of plans ease the discussion and decision-making (Benson 1992; Berkowicz 2000; USEPA 1998). Therefore, coupling air quality modelling with mapping and health risk assessment is useful as an integrated planning and management tool.

Air quality modelling has a rich history and has evolved rapidly with new methods and approaches tested and applied in many situations and conditions. The advancement of air quality modelling allows to predict with increasing accuracy the air quality at a particular places and a specific time. Various modelling approaches coupled with monitoring data are used, from simple analytical to empirical modes to complex numerical models (Brzozowski 2006; Vardoulakis et al. 2003). To increase accuracy, air quality modelling also became increasingly sophisticated with more details data required on different aspects, not only the obvious ones such as atmospheric data, pollution sources, etc. but also land-use, demography and socio-economic data are integrated. These later are also extensively used in domain, as socio-economic planning, social studies, landscape studies, urban studies, and transportation. The overlapping is evident but the types of data required are often different among the different domains.

Economic growth and the fast motorisation rate are the main drivers of air pollution in urban areas. The use of HIA to address the problems and to find solutions gained substantial ground and needs to be strengthened further so that development plans and policies will fully take health issues into account. The approaches to HIA need to be investigated and suitable tools need to be designed allowing to integrate HIA at its full potential in the decision-making.

In Vietnam, these integrated tools are not well developed and utilized. While the application of GIS and environmental modelling has been integrated in environmental research, they are not used in health assessment. Therefore, while there are numerous studies on air pollution and the fate of air pollutants in the environment (Pham 2005; Hung et al. 2010; Hoang 2008), these results have not been used to assess the impact of air pollution on human health. Applying GIS and environmental modelling to quantify health impacts of air pollution will bring significant improvements, such as the incorporation of time and space in health impact assessment, which in turn will provide better and quicker results.

1.2.2. Research questions and objectives

The use of models and GIS in a health risk assessment, from the governance point of view, can reduce the waiting time for results, in comparison to the in depth personal exposure study with better accuracy than using purely monitoring data and health statistics. The use of models and GIS also allows summarising the links between air quality and health outcomes visually and is therefore useful in the decision-making on urban planning and development.

Therefore, the main research question of this work is to investigate the possibilities of integrating GIS and air quality modelling in HIA to form a coherent procedure that can be generalised and applied in different contexts. The focus will also be on assessing the use of indicator pollutants in this integration. The final aim is to improve HIA results through the integration of GIS and modelling in the HIA methods.

The secondary question is to investigate which improvements can be made to further advance the integration and facilitate the application of integrated modelling in policy-making. As the integration of GIS and modelling will require a coupling of various data sources and layers, it is hypothesised that improvements are possible for at a number of entries.

The overall goal of the research is to contribute to decision making on urban planning by providing scientific evidence on the health effects of air pollution caused by transport and mobility development plans using strategic environmental assessment (SEA). The main research question of this study is how to integrate GIS and modelling in the process of health impact assessment in urban settings.

The research is based on the hypothesis that the integration of environmental modelling, GIS and health impact assessment in an SEA context may provide objective and accessible results on the possible health impacts of air pollution caused by mobility and transport in the economically fast developing centre of Hai Phong, Vietnam.

To achieve this overall goal, the research has following specific objectives:

1. To develop an air pollution assessment model for the Hai Phong area.
2. To investigate and quantify the health effects of air pollution associated with mobility and transport activities.
3. To assess the health impacts caused by different scenarios of transport and mobility development in Hai Phong and Hanoi, Vietnam.

1.2.3. Human Ecology Approach

Environmental problems are often highly complex as people involved have different concerns and engage in different activities that interact with the environment and therefore can drive the problems in different directions. The interactions between the societal actors and the environment are the core of a research field termed as "human ecology".

Human ecology has an academic developments spread throughout a range of disciplines, including biology, geography, sociology, psychology (Pires and Craveiro 2010). Each of the disciplines studies human and its position in the ecological, social and built environment differently. Initially, in biology and geography, humanity is seen as part of the natural systems that subject to an adaptation to biological and environmental conditions (Thrower 1999; Catton 1994; Pires and Craveiro 2010). Later on, sociology influenced human ecology by adding elements of demographical evolutions, urbanisation and social heterogeneity. This progress is notable at the Sociology Department of the University of Chicago (Gross 2004; Park, Burgess, and McKenzie 1925; Lawrence 2003). These authors emphasized the difference between human ecology and ecology in general by highlighting cultural evolution in human societies (Young 1974). Their works led to many other studies that try to explain the distribution of populations in urban areas using ecological and zoological approaches. Follow-up studies emphasise the revitalization and conceptual work and thereon define human ecology as the study of interdependencies between society and environment with many focuses on population, environmental and cultural dynamics (Hawley 1986). Lawrence (2002) defines human ecology as "*an holistic, integrative interpretation of those processes, products, orders and mediating factors that regulate natural and human ecosystems at all scales of the earth's surface and atmosphere*".

Urban Ecology is an integrative branch of sciences, rooted in ecology and focuses on a broad conception of urban ecosystems which include not only the urban core but also the less densely populated suburban areas where the fluxes and interactions that affect and are affected by the urban core (S T A Pickett et al. 2011; Wittig and Wittig 2009). Urban ecosystems encompass both the biotas and the societal and built environments within the urban landscape (Steward T. A. Pickett et al. 2015; Wittig and Wittig 2009). Urban ecology therefore links closely to human ecology, where human ecology is studied with a focus on urban environment.

This research corresponds to a number of characteristics of a Human Ecological and Urban Ecological study, which is the study on the interrelationships between humans and their (urban) environment. It encompasses first of all the **interdisciplinary** character, which lies at the centre of all Human Ecological research by combining different subjects, including environmental, health, and policy aspects. The combination happens not only on the subject front but also at the methodological level where environmental and health methods are combined using modelling and GIS. Policy recommendations come out as the result through trends and scenarios studies.

By targeting the integration of methods, this study aims to provide a better understanding of the **complexity** and a more comprehensive outlook on the problem as compared to disciplinary approaches. These integrations show how this study embraces the core principles of the Human Ecological approach and provide outcomes that are **relevant for the society** and **applicable in policy decisions** for a better environment and human health.

1.3. Research framework

This research wants to establish a systematic framework to assess the impacts of air pollution due to urban traffic. As shown in Figure 9, there are two major elements: The first assesses air quality in relation to urban traffic in Hai Phong and Hanoi. This includes quantifying air pollutants and identifying the levels of pollution at different locations. The second assesses the health risks related to traffic-contributable pollution using conventional Health Risk Assessment framework.

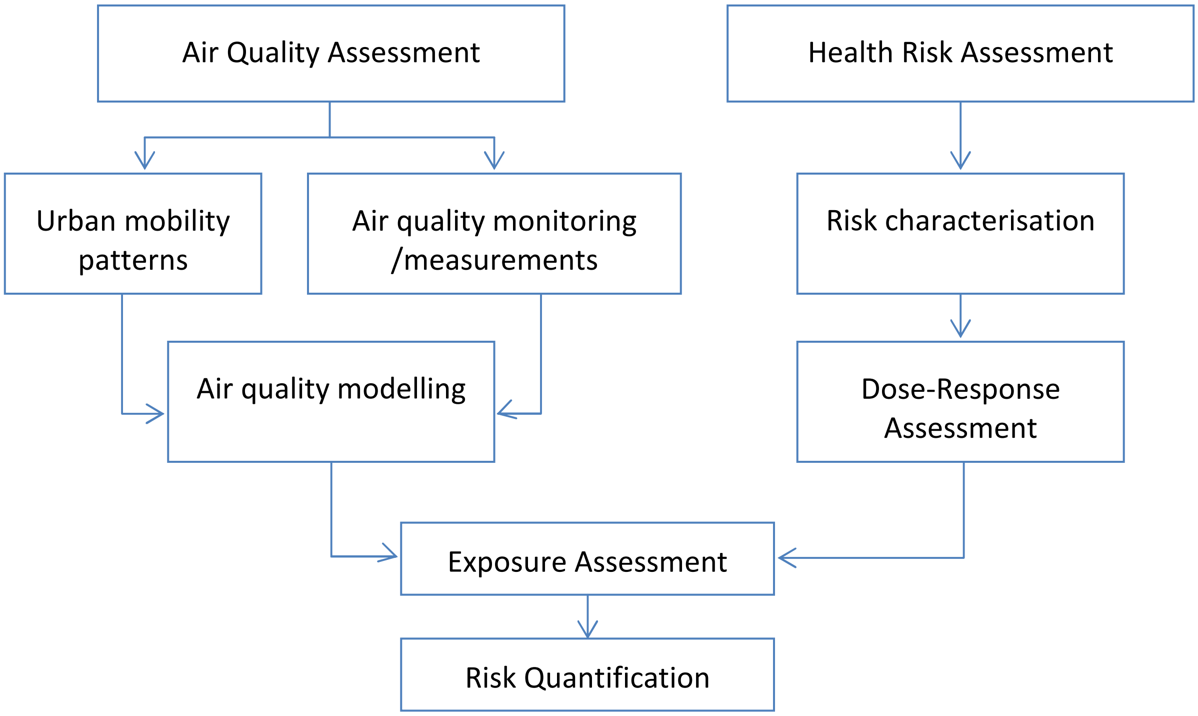

Figure 9. Impacts of urban transport on human health - A research framework

Assessing air quality (and mapping air quality) uses a combination of air quality monitoring data and modelling results. The main outcome of this assessment is the air quality map, which allows assessing the exposure to air pollution (in this case is PM). The quantification of health risks is the second element and uses a Health Risk Assessment methodology, which entails 4 components: Risk Characterisation, Dose-Response Assessment, Exposure Assessment and Rick Quantification. The process allows quantifying the health effects of air pollutants based on established dose-response functions in literature, coupled with detailed exposure assessment using integrated approaches which combine air quality data and exposure data. Dose-response functions are available for many air pollutants in the literature. However, it is not always possible to tie each health effect to a single pollutant as they often interact and in combination shows synergistic health effects. Therefore, to avoid double counting of adverse health effects related to air pollution, particulate matter is considered as the indicator pollutant in this work to quantify health outcomes. For mental and well-being, only the effects of noise can be quantified in this study using mapping and modelling methods. Other effects are reviewed but need more empirical research before it is possible to quantify them.

1.4. Expected outcomes and thesis structure

1. **An air quality map for Hai Phong area using an adequate modelling method.** Many studies have been done to improve the results of each step of the Health Risk Assessment framework, including studies on exposure assessment, dose-response relation and risk quantification. Mapping has been used to produce high quality maps of traffic-related air pollution both for exposure assessment and the subsequent policy making. However, mapping of traffic-related air pollution is not easy, as the street level concentration of pollutants varies across space and time and pollution patterns in urban areas are complex. Monitoring data on urban air pollution are often sparse, mostly due to a limited network of monitoring stations. Modelling can provide the missing links in producing map of urban traffic-related air pollution covering a whole area. *Chapter 2* describes the methodologies applied to model traffic-related air pollution in Hai Phong. The results are used to assess exposures to traffic-related air pollution and to quantify health risk which are associated with urban traffic.

2. **Assessing the health impacts of mobility and transport in Hai Phong and Hanoi.** *Chapter 3* presents the results of a health risk assessment that quantifies the mortality and the main diseases associated with air pollution (particulate matters, benzene, noise) resulting from transport. The focus is on the integration of modelling and GIS approaches in the process of exposure analysis with the aim to increase the accuracy of the assessment. The results of the assessment support the decision-making process on urban planning and contribute to a more sustainable mobility in Hai Phong. Furthermore, *Chapter 4* presents a similar approach applied in Ha Noi, as an extra application to pinpoint the advantages and disadvantages of modelling and HIA for cities of different size.

3. Finally, the *Chapter 5* **Discussions** and **Conclusions** presents the finding of the research and provides a critical look into how integration approach can be implemented in Vietnam. This chapter reconfirms that health is the result of not only of individual characteristics and lifestyle but also of the socio-economic or physical environment and therefore, decisions in all policy areas will affect people's health. HIA allows identifying the future health consequences of those policies through predicting 'potential effects' and the use of modeling and GIS as a common platform for different assessments to reconcile and combine various assessment processes into an integrated assessment is gaining momentum. The chapter makes it clear that the use of models and GIS in a complete health impact assessment process is advantageous in various ways and will allow to understand the links between air quality and health outcomes. The chapter provides also recommendations for improvements that can be made to further advance the integration.

CHAPTER 2. APPROACHES, MATERIALS AND METHODS

2.1. Study areas

Two cities in Vietnam were chosen for this study based on both their strategic locality as well as the practicality of the research. Hai Phong is a fast growing port city, which has seen an upgrade in status (from a provincial city to a Level 1 Centrally-governed city) that proves its importance in the regional development scheme. Meanwhile, Ha Noi is the capital city of Vietnam, which has all the focus for development since the start of the 'open-door' policy. The two cities are very different geographically, structurally as well as developmentally. However, they also have many similarities in the way road transport has been developing.

2.1.1. Hai Phong City

Hai Phong is a coastal province, located in the East of the Northern coastal area of Vietnam, 120 kilometres southeast of the Capital Ha Noi. Hai Phong has a surface area of 1,519.2 square kilometres. The city is surrounded by Quang Ninh, Hai Duong, Thai Binh provinces and the South China Sea. It is the third largest city in Vietnam (after Ho Chi Minh City and Hanoi), hosting a population of 714,000 in 2005. By 2006, the urban population accounts for about 41% of the total population in the province. Hai Phong as a province has 5 urban districts (Hong Bang, Le Chan, Ngo Quyen, Kien An and Hai An, forming Hai Phong City), 1 town (Do Son) and 8 rural districts (Thuy Nguyen, An Duong, An Lao, Tien Lang, Vinh Bao, Kien Thuy, Cat Hai and Bach Long Vy.

Hai Phong has an advantageous location as the main gateways into the Northern Vietnam. Airborne, waterborne, road and rail transport provide the city with a multimodal transport system. This mobility system is a main driver of its fast economic development. Recent upgrading of the National Route No. 5, the expansion and modernization of the port system, and entirety improvement of the Cat Bi Airport, added to the existing mobility assets. In this way Hai Phong affirms its capacity as the import-export gateway for the whole Vietnamese Northern Delta.

Hai Phong pursues a progressive development towards the largest port-city in the North of Vietnam and profiles as a modern city, as one of the national urban centres, as a main gate to the sea and as a centre of industry, trade, tourism, services and aquaculture of the Northern Region (Hai Phong Authority, Development Plan, 2005). The future development strategy will strengthen economy towards industrialisation and modernisation with well-developed infrastructure, with a rapid, sustainable and effective economic growth and an average GDP growth of 14% for the period 2010-2020. This growth rate is planned to be realised mainly by the service sector, industry and construction. By 2020, the urban population of Hai Phong will be around 85% of the total population. Transportation is an important sector, which links the port with the hinterlands. The strategic development plan of Hai Phong provides a view on infrastructure development for transportation towards 2020, including an additional highway to connect with Ha Noi Capital, an upgrade of the link from the highway to the city and three ring roads, a new bridge which connects the left bank with the city centre, a new coach station and a ferry port.

In Hai Phong, in 2003 transportation accounts for around 90% of the total emissions of lead, around 60% of the total emissions of nitrogen oxides, and around 50% of the total emissions of carbon monoxides. Transportation also accounts for around 25% of total emissions of particulates with diesel engines as the main emitters (Hai Phong DOSTE, 2003). A monitoring network on air quality was established at 19 intersections and other areas (parks, streets and a stadium) during 2007. The monitoring results showed that the air is polluted by CO values exceed the Vietnamese standard 5937:1995 for ambient air quality by a factor between 1.2 to 2.6; while the NOx emissions are still within the limit of Viet Nam’s ambient air quality. The highest values are measured during the period from March till December. The concentrations of hydrocarbons in Hai Phong city were high, especially in the summer months, possibly due to the increase in air temperature. The Total Suspended Solids (TSP) values range below the limit of Viet Nam’s air quality standard but exceed the threshold for health impact to occur. As compared to monitoring data collected in 2001, the air quality in Hai Phong City steadily decreases. The CO concentration in Hai Phong’s air increased between 2001 to 2007. Similarly, there was an increase of NOx in Hai Phong’s air from 2001 on. This indicates that the air quality of Hai Phong is progressively worsening. The major environmental aspects associated with mobility in Hai Phong are related with the complicated intra-city transport network that is overloaded and causes congestion during the rush hours, which in turn leads to the increase in air pollution. The poor technical quality of some vehicles also contributes to emissions of dust, hydrocarbons, NO_x, SO_x, O_3, and reduces traffic safety. All these impact human health. Public transit services in Hau Phong are inadequate and traffic management is poor. Coupled with limited awareness among the inhabitants and lack of implementation of traffic laws, the situation increases unsafely, resulting in deaths, injuries, and damaged property.

The expected increase in motorized transport and the demographical densification of the urban areas, air pollution driving continuing transport related health risks also in the future. This necessitates a study on the impacts of air pollution from traffic and mobility on the public health. As compared to the health impact thresholds for various air pollutants and effects, it is expected that Hai Phong might have a significant health burden. The information on the trends in air quality and their relation to health risks should be provided to policy-makers and public managers (authorities). They should deal with it in their sustainable development plan.

2.1.2. Ha Noi Capital

Hanoi is the capital of Vietnam and the second largest city in of the country, just behind Ho Chi Minh City. During the last two decades, Hanoi developed fast on all fronts, and expanded steadily. Hanoi changed its administrative boundaries 4 times in 1961, 1978, 1991 and 2008. After the last boundary modification, Hanoi covers a total area of 3,348.5 km^2; has a population of 6.45 million people with an average density of 1,926 people/km^2, which is distributed over 27 districts (9 urban and 18 rural) and 408 communes (as by 31 December 2008) (Hanoi Statistics Office 2009).

Hanoi experiences a 11.69‰ population growth a year in 2000, which increased to 11.75‰ in 2005, 12.46‰ in 2008 and 12.67‰ in 2009. Hanoi has a fast urbanisation rate, achieving 5.6%/year during the period 2001-2005 but reduced to 2.96% during the period 2006-2009. By 2009, the urban proportion was 40.8%, a figure which increased from 33.2% in 2000 (General Statistics Office 2011)(Statistical Year Book of Hanoi, 2008). In 2006, Hanoi had an unemployment rate of 6.06%, which declined to 5.35% in 2008. Hanoi has about 3,974 km of roads, of which 643km within the 9 old districts (that account for 6.8% of the urban area).

Since acquiring a large part of the surrounding provinces in 2008, which is primarily rural area, Hanoi tripled its size and doubled its population. The new development aims spreading the concentrated population and economic activities to the newly acquired areas to alleviate air, noise and water pollution and the decreasing quality of life of the residents. Hanoi is a highly polluted city as a result of the high density of traffic and the many inner city factories. The fast transition from bikes to motorcycles and to cars increases environmental burdens on the air quality and human health.

Hanoi has a very fast growing (12%-15% increase per year) fleet of motor vehicles (Vietnam Register 2010). Both the number of cars and motorcycles increases rapidly. In 2000, Hanoi had around 46,200 cars/trucks, accounting for 9.5% of the country's total vehicle fleet. Its 865,232 motorcycles comprise 12.38% of the country's motorcycle fleet. By the end of 2009, it is estimated that more than 2.76 million motorcycles are in circulation (Vietnam Register 2010).

The average levels during 1996–1998 for $PM_{2.5}$ and PM_{10} at a monitoring site in Hanoi were 35 and 50 $\mu g/m^3$, respectively (Hien et al. 2002). The annual mean concentrations from August 1998 to July 1999 were 87.1 (±3.1) $\mu g/m^3$ for PM10 and 36.1 (±1.3) $\mu g/m^3$ for $PM_{2.5}$. Data for the period 2001-2004 shows an averaged concentrations of PM_{10} in Hanoi for the dry season was 186 $\mu g/m^3$ and for the wet season was 79 $\mu g/m^3$ (Kim Oanh et al. 2006). Hourly average concentrations of PM_{10} at the urban background station in Lang for 12 months in 2007 show an average PM_{10} of 139.5 $\mu g/m^3$ (Hung et al. 2010). These data clearly shows the increasing trend of the PM_{10} concentrations in Hanoi.

Motorcycles are a major source of emissions. Motorbikes totalises a 92-95% of all vehicles (Hung et al. 2010) and account for 97% of all passenger trips (Guttikunda 2008). Motorbikes contribute 56% of NOx, 65% of SO_2, 94% of CO, 92% of benzene, and 86 % of the PM_{10} exhaust emissions. The highest emission load is for PM_{10} and is dominated by emissions from paved roads (Hung et al. 2010).

The modal share of motorcycle among the commercial trips is high at 60%. Registered motorcycles in Hanoi are increasing at 13,5% per year (Guttikunda 2008). Higher concentrations of PM_{10} occur along the roads, during both dry and wet seasons, in Hanoi (Kim Oanh et al. 2006). Congestion is popular in Hanoi and the air quality in streets during congestion is approximately 10 times the Vietnamese standards indicating serious air pollution (Hung et al. 2010).

2.2. Air Quality Assessment

2.2.1. Overview

The growth of traffic, especially in urban areas puts increasing pressures on urban governance. The challenge is developing a policy and management curbing the health effects of traffic-related air pollution. This requires an in-depth understanding of air pollution in city, especially in residential areas adjacent to roads.

Mapping of traffic-related air pollution is not easy, as the street level concentration of pollutants varies across space and time. Pollution patterns in urban areas are complex. Monitoring data on urban air pollution is often sparse, mostly due to limited human and financial capacity to manage an intensive network of fixed and mobile monitoring stations. Modelling can provide the missing links in producing an accurate map of urban traffic-related air pollution. Mapping has been used to produce high quality charts of traffic-related air pollution both for exposure assessment and policy decision-making.

To model traffic-related air quality, three modeling modules are needed. First, traffic patterns need to be assessed using a transport model. Transport models use data on the transport network (or road network, including data on the type of roads/rails, travel directions, number of lanes, junctions, etc.) and the actual and forecasted total traffic (including traffic modes, directions and intensity) to model the distribution of traffic over time. The outcomes of the transport model provide an estimation of the number of vehicles (by type, e.g.: cars, trucks, motorcycles, etc.) on each section and in each direction of the road network at a specific time point. These data are used as an input for the emission module. This second step provides information on the quantity of the studied air pollutants that is emitted, by section of the road network during a specified period of time. The third module addresses a dispersion model. This is a mathematical simulation describing how the emitted air pollutants disperse in the atmosphere and provides data on the concentrations of air pollutants at a specific location during a defined timeframe. The dispersion model uses data provided by the emission model and the data on meteorological situation (often daily observations). These are combined in a GIS (road network, administrative data) and calibrated using air quality measurements. Figure 10 describes the sequence of the modeling modules as well as inputs and outputs for each module.

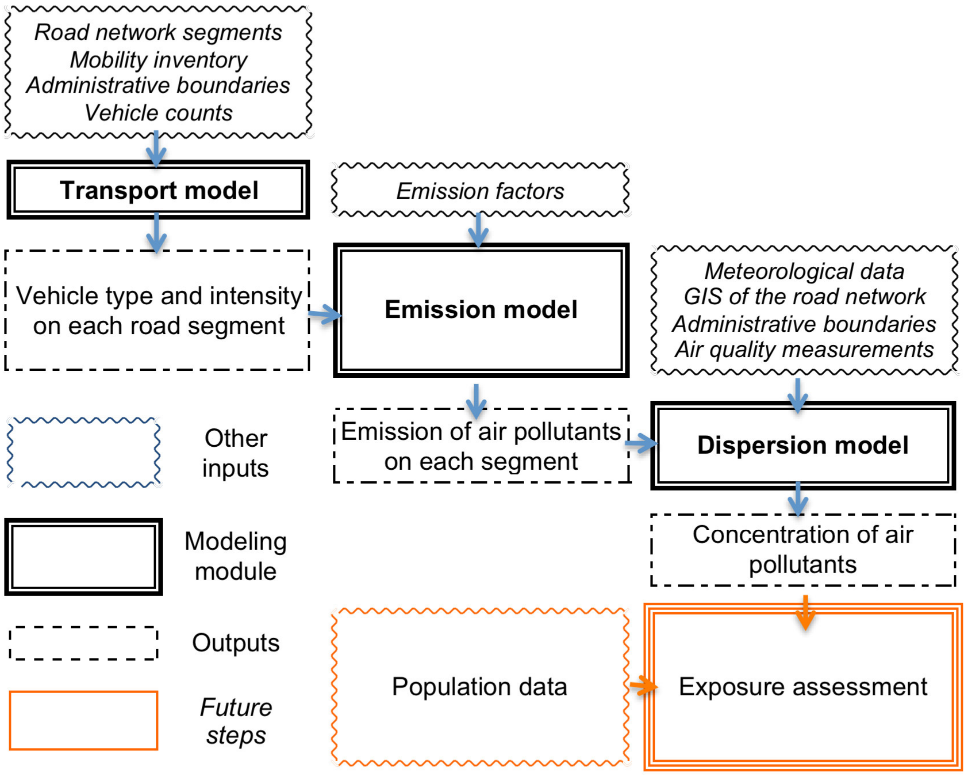

Figure 10. Modelling modules

Often, emission models can be incorporated as a sub-model in either transport models or dispersion models as a step further (in the former case) or as an input step (in the later case).

2.2.1.1. Transport models

Two main groups of transport models are currently in use forecasting transport. The most traditional group of models is the sequential four-step model [sometime called urban transportation planning (UTP) procedure] (McNally 2007; Ziliaskopoulos and Mitsakis 2008). It was first implemented on mainframe computers in the 1950s for the Detroit Metropolitan Area Traffic Study and Chicago Area Transportation Study (CATS). Typically, forecasts are made for the region as a whole, where the region is divided into zones. Population and employment are main determinants. The four steps of the classical 4-step model include:

- Trip generation: This step determines the extent of daily travel at the levels of household and of zone. It is based on data of land use, household demography and socio-economies. The travel coverage and volume are calculated using the frequency of the origins (or destinations) of trips in each zone by trip purpose.
- Trip distribution matches origins with destinations, often using a gravity model function (or attraction between different origins and destination, equivalent to an entropy maximizing model). The result of this step is usually a trip matrix (or origin-destination matrix – O-D matrix).
- The mode choice is the proportion of trips between each origin and destination for a particular transportation mode (walking, bicycle, motorbike, car, bus, train, tram, etc.). A calibration using data from transport surveys can be done fine-tuning the choices.
- Traffic assignment allocates trips between an origin and a destination by a particular mode on a specific route. Different rationales exist behind the choice of a specific route, such as the Wardrop's principle of user equilibrium or a Nash equilibrium, wherein each driver (or group) chooses the shortest time path.

The most important uncertainty of this model is linked with the inputs. These data inevitably include an error, such as sampling bias, survey design, coding mistakes or incomplete information (Rasouli and Timmermans 2012). This can be reduced through a calibration process using actual traffic count data.

The second class of transport models is activity-based and predicts which, where, when and for how long specific activities (e.g. work, leisure, shopping, etc.) are conducted by each user. These models also predict which mode or modes of transport will be chosen and which routes are used (Rasouli and Timmermans 2012; Shiftan 2010). These models are based on the hypothesis that travel demand is driven by activities that people need or wish to perform, with travel decisions is a part of the scheduling decisions (when an activity is undertaken and what is the sequence of the activities). Traffic flows are simulated using time-dependent origin-destination tables projected on the networks using conventional assignment algorithms. This is done using traffic micro-simulation models (or agent-based). These latter require heavy data inputs and are subject to both input and model uncertainty (Rasouli and Timmermans 2012).

Both four-step models and activity-based models offer other possibilities such as modeling environmental issues (emissions, air quality and exposure to air pollution). Activity-based models provide a more reliable estimate of individual exposure as compared to four-step models. Therefore they describe more precise relationships between health impacts and air quality. As the consequence, this modeling method requires a huge input of data on individual activities over a long period of time, and is therefore very time and resource demanding. Meanwhile, four-step models are much easier to apply both in term of data collection and in term of model run.

2.2.1.2. Dispersion models

Dispersion models are generally built using Gaussian plume equations (they are therefore also called Gaussian models) (Jerrett et al. 2005; Bellander et al. 2001). These models assume that air pollutants spread in a deterministic way. The inputs of dispersion models are emission data, meteorological conditions, and topography. When coupled with GIS, these models allow the combined analysis of information from empirical monitoring, data on the population distribution, the road network, and traffic observations. The result is a more realistic representation of exposure data which subsequently are used in health risk studies (Jerrett et al. 2005).

Different dispersion models have been developed during recent years. Most widely used are CALINE models (Craglia and Couclelis 1997); the Operational Street Pollution Model (OPMS) (Sokhi 1998; Berkowicz 2000), and the AERMOD model (Cimorelli et al. 2004).

CALINE4 is a line source Gaussian-based dispersion model that was developed by the Californian Department of Transportation. The model presents a line source as a series of finite length elements that are oriented perpendicular to the wind. The length of each element is determined by its distance from the receptor. CALINE4 models are used issuing regulations on the dispersion of CO and PM long roads (Craglia and Couclelis 1997).

The Operational Street Pollution Model (OSPM) is used to simulate the dispersion of air pollutants in the street canyons. It was developed by the National Environmental Research Institute of Denmark, Department of Atmospheric Environment. The OSPM calculates the concentrations of traffic-emitted pollution using a combination of a plume model for the direct contribution and a box model for the recirculating part of the pollutants in the street. OSPM models are designed to produce time series of pollutant concentrations within near-regular canyons. They are based on empirical assumptions and parameters that need to be recalibrated using field measurements when applied in new locations (Vardoulakis et al. 2003).

The ISC3 - Industrial Source Complex model is a part of the AERMOD model pack which can be used in studies on traffic air pollution in urban areas. The ISC model is widely used and broadly applicable to multiple source types. ISC3 exists in two variants, the short-term (ISCST3) and the long-term (ISCLT3) models. Comparison of both models shows that they yield similar results on predicting monthly and quarterly average concentrations: both models predicted lower concentrations than the observed ones. ISCST3 predicts concentrations which approach the observed ones closer. Therefore the model is better estimating long-term concentrations of sulfur dioxide as compared to the ISCLT3 model (Kumar, Bellam, and Sud 1999). In this thesis, the ISC3ST is used because it has been widely applied and validated in studies on traffic air pollution in urban areas and EIAs for transport projects in Vietnam (Hoang 2008). Other available line source models such as CALINE3, CALINE4 and HYROAD are limited to a maximum of 20 links for each single run. Therefore, they are less indicated studying a complicated road network like the one in Hai Phong with more than 1700 links. Moreover, ISC3ST’s data requirements fit with the data available for Hai Phong. The ISC3ST uses daily traffic (vehicle volume, types and density of traffic) and meteorological data (wind direction, velocity and mixing height).

Bellander et al. (2001) suggest that dispersion models are useful in the assessment of retrospective individual exposure of air pollution. This approach has also been used by other authors such as Nafstad et al. (2003, 2004). Dispersion models have the potential advantage of incorporating both spatial and temporal variation of air pollution within a study area without a need for dense monitoring networks (Jerrett et al. 2005). The models can also be applied at different spatial scales. At the urban scale, dispersion models are used to describe air pollution episodes, while at the regional scale they allow assessing the transfer of pollution between regions. These models provide high-resolution analyses of patterns which can be used calculating health and environmental effects. They can be applied with relatively minor changes for different study areas (Bellander et al. 2001; Jerrett and Finkelstein 2005). The disadvantages of these models include a relatively costly data input; assumptions about dispersion patterns (i.e., Gaussian dispersion); a need for extensive cross validation with monitoring data; and temporal mismatches in data which may cause estimate errors (Jerrett et al. 2005).

2.2.2. Models used in the Hai Phong case study

Considering the advantages and disadvantages of the different types of models, and taking into account available human and financial resources for this thesis, a choice of model for each module was done. The most important selection factor is the accessibility to the model and the availability of data.

For the transport model, VISUM® transport is used. This model is based on a mobility survey carried out in Hai Phong in 2007. The model requires an O/D (Origin/Destination) matrix, quantifying the mobility demand and the description of the road graph. Hourly traffic fluxes are obtained from peak results using empirical coefficients estimated for the whole net. The model results are calibrated with on site traffic measurements.

An emission model has been developed on the basis of the results shown by Borrego et al. (2003). The formula used to determine the emissions per link is:

$$E = \sum_i V_i L E_f$$

Where: **E** is the total amount of emissions of a particular pollutant per link (g/s); ***i*** is the vehicle type (car, truck, bus, motorcycle); V_i is the volume of the vehicle type *i* along the link; ***L***is the length of the link (km); E_f is an emission factor of vehicle type *i* (g/km).

Emission factors (E_f) for free-flowing conditions (g/km) were obtained from the Indian National Environmental Engineering Research Institute (NEERI) (Sivacoumar and Thanasekaran 2000) considering the similarity in vehicle fleet and conditions between India and Vietnam.

For the dispersion model, the ISC3ST was used. The basis of the ISC3ST model is the straight-line, steady-state Gaussian plume equation. It is a multi-source dispersion model for point area, volume and open pit sources. The volume sources, as an output of the emissions model, were transferred to ISC3ST, subsequently modelled and presented as line sources (USEPA 1995). The line sources are approximated using elongated area or volume sources close to each other.

2.2.3. Data collection

For the three modeling modules, various data is needed. Some data is unique for each model (meteorological data for dispersion model) while other data is needed across models (e.g. demography; road network configurations). The data all belong to one of the three categories: spatial data, traffic data and demographic data.

2.2.3.1. Spatial data

The GIS map of Hai Phong (e.g.: boundaries of the study area) and its road network was built based on the available administrative and road network maps in Hai Phong. For the road network, a modification was introduced segmenting the current roads (situation in 2007) into links and nodes, which is required to run the transport model. The road network data was digitalized based on the data provided by the Hai Phong People Committee.

As required by VISUM, in the GIS map, nodes and links are defined for the whole road network in Hai Phong. Nodes determine the locations of street junctions and each node is identified by its geographical location. A link is a section of the road or rail network between two nodes. Nodes are the start and the end of links. Optionally, a major flow can be defined for every node specifying the direction of the flow with the right-of-way and can be determined automatically by VISUM from the ranks of the intersecting links.

Links describe roads or rail tracks of the transport network. Aside from the properties of nodes attached to a link, other physical properties of a link include its length and width. A link can be directional and is an independent network object. For each link, the permitted transport modes (public and private) are specified. Both links and nodes are associated with administrative properties (official name and the commune that the link belongs to).

2.2.3.2. Traffic data and situation

The VISUM model runs on a set of geo-referenced data on the urban road network of HaiPhong and the data on different administrative zones (commune) in HaiPhong. Data on the urban road network includes information on the road ID and road types (urban street, provincial road, national road). As stated above, different modes of transport can use a specific link. The five different modes of transport included in the transport model are Bus (Public Transport - PuT), bicycle (Private Transport - PvT), car (Private Transport), motorcycle (Private Transport) and walking (Private Transport). For each mode, the parameters listed in Table 3 characterise a transport system. They are occupancy rate, analysis period, maximum speed and type (public or private).

Table 3. Attributes characterising the transport system

Transport mode	**Occupancy rate (people/vehicle)**	**Analysis period**	**Speed (Vmax) (km/h)**	**Type**
Bus	45	365d – 12h	20	PuT
Bicycle	1-2	365d – 24h	15	PrT
Car	1-4	365d – 24h	50	PrT
Motorcycle	1-2	365d – 24h	40	PrT
Walking	1	365d – 24h	5	PrT

Traffic data includes vehicle volume, types and density of traffic and was collected using the vehicle count method. Vehicle counts were performed in 2007 at 20 locations. The data allowed calibrating the model. The Figure 11 below shows the locations where the air quality is monitored and the traffic counts are performed. Most of the monitoring points are used for both traffic count and air quality measurements.

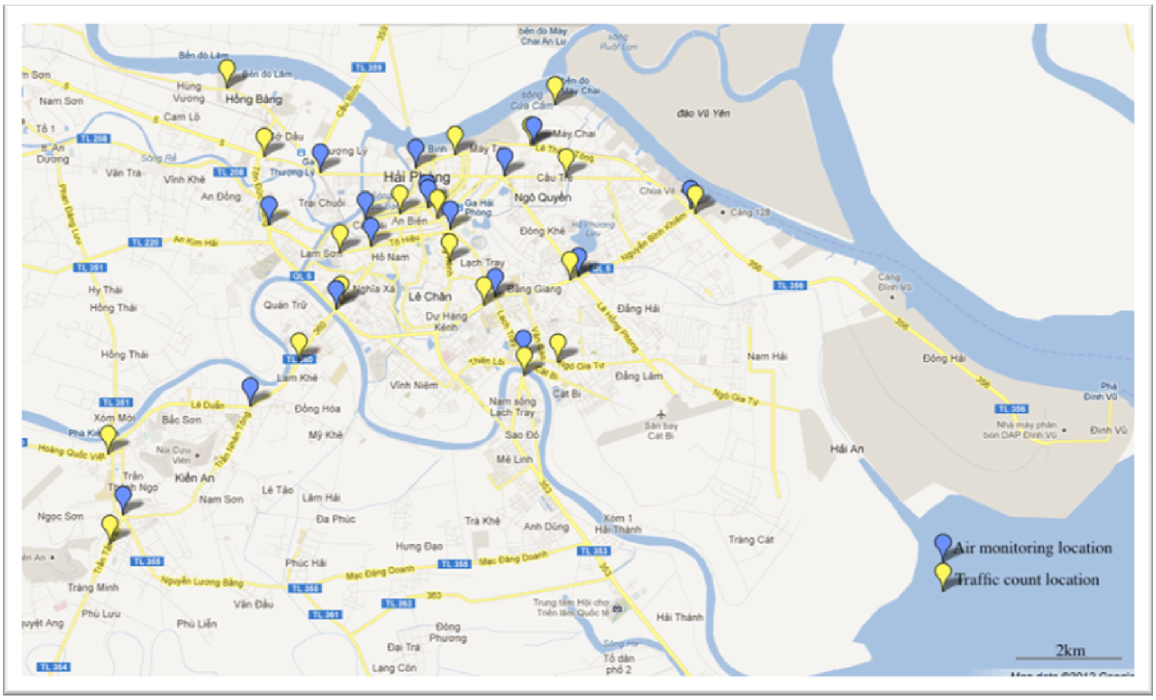

Figure 11. Air quality monitoring and traffic count locations

During the traffic count campagnes, 5 types of vehicles were considered: buses, trucks, container lorries, passenger cars (< 9 places), and motorbikes. At each of the 20 counting points, three counting sessions using filming were performed three times a day: morning, afternoon and night. Each session lasts 20 minutes. An hourly average was calculated.

Table 4. Traffic count results

Counting station ID	Counted (Average total vehicles per 20 minutes)
1	588
3	584
4	151

Counting station ID	Counted (Average total vehicles per 20 minutes)
5	1493
9	385
10	147
11	2072
12	662
13	337
14	409
17	1457
18	1445
19	618
20	1479

2.2.3.3. Demographic data

Demographic data of the official statistics of the Hai Phong Government was used (Hai Phong Department of Health 2007). Hai Phong has five urban districts, one town and eight rural districts. The five urban districts are Hong Bang, Le Chan, Ngo Quyen, Kien An and Hai An. The only town is Do Son[3]. The eight rural districts are Thuy Nguyen, An Duong, An Lao, Tien Lang, Vinh Bao, Kien Thuy, Cat Hai and Bach Long Vy. By 31/06/2006, Hai Phong had 1,812.7 thousand inhabitants, with an average density of 1,193 people/km^2. The urban population accounts for around 41% of the total population. By 2007, 598,027 people lived in the five urban districts.

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[3] Town is a second level administrative unit in Vietnam, under the governed by the province and is officially categorized as Class III or Class IV of urban regions by Vietnam government, and is at the same level with urban districts, which are governed by centrally-administered municipalities.

Table 5. Demographic data of the Hai Phong urban area

	Area (km^2)	Populationn 2007 (people)	Density (ppl/km^2)	Number of commune
Urban area	169.80	598,027	3521.95	52
1. Hong Bang	14,5	74,461	7152.96	11
2. Ngo Quyen	9,57	103,718	16665.41	13
3. Le Chan	11,31	171,774	15187.80	13
4. Kien An	29,58	88,586	2994.79	9
5. Hai An	104,84	159,488	710.23	6

Among the five urban areas, Ngo Quyen and Le Chan have more than 15,000 people/$km^2$and are the most densely populated districts. The district with the lowest population density is Hai An, with a density of one-fifth of the city's average. There are 52 communes within these 5 districts (Table 5). Hai Phong faces an increasing urban population and a decreasing rural population. However, these changes are insignificant. From 2000 to 2006 the urban population increased by 6%. The natural growth rate in 2006 was 9.98‰ in the urban area and 9.23‰ in the rural area. In 2005, these population growth rates were 8.18‰ and 11.99‰, respectively.

More detailed data at the commune level of the 5 urban districts of Hai Phong was collected (Table 6). They include information on district and administrative precincts (or commune). For each precinct, the perimeter, surface, population and density were identified. The perimeter of each commune is calculated through the digitalizing of administrative maps.

Table 6. Main demographical data by district in Hai Phong

DISTRICT NAME	COMMUNE NAME	AREA (km^2)	POPULATION (people)	DENSITY (people/ km^2)	PERIMETER (m)
Hai An	Dang Hai	3,08	8026	2626	8355,658
Hai An	Dang Lam	5,16	11337	2197	14380,594
Hai An	Nam Hai	5,74	7654	1333	12188,201
Hai An	Cat Bi	1,20	21146	17621	5257,117
Hai An	Trang Cat	29,26	8279	283	20470,252
Hai An	Dong Hai	60,40	18019	298	0,000
Hong Bang	Quan Toan	2,44	8966	3675	8598,409
Hong Bang	Hung Vuong	4,34	10072	2321	10226,984
Hong Bang	So Dau	3,28	11945	3642	8456,754
Hong Bang	Thuong Ly	1,58	18127	11473	5738,685
Hong Bang	Ha Ly	1,08	14263	13206	4424,921
Hong Bang	Trai Chuoi	0,41	10122	24688	3060,086
Hong Bang	Pham Hong Thai	0,15	4283	28553	1491,082
Hong Bang	Phan Boi Chau	0,16	7525	47031	1791,452
Hong Bang	Quang Trung	0,14	6589	47064	1910,841
Hong Bang	Hoang Van Thu	0,29	5294	18255	2713,860
Hong Bang	Minh Khai	0,63	6532	10368	4294,460
Kien An	Quan Tru	3,34	18750	5614	11995,514
Kien An	Dong Hoa	3,57	5364	1502	9099,629
Kien An	Bac Son	2,29	11250	4913	7905,350
Kien An	Nam Son	3,68	8056	2189	10122,326
Kien An	Ngoc Son	3,50	5817	1662	9847,701
Kien An	Tran Thanh Ngo	1,18	11537	9777	5840,236
Kien An	Van Dau	4,63	12100	2613	12588,615
Kien An	Phu Lien	3,53	7382	2091	11453,959
Kien An	Trang Minh	3,86	8330	2158	11752,279

DISTRICT NAME	COMMUNE NAME	AREA (km^2)	POPULATION (people)	DENSITY (people/ km^2)	PERIMETER (m)
Le Chan	An Bien	0,31	12154	39206	2909,655
Le Chan	Cat Dai	0,33	10137	30718	2543,421
Le Chan	Trai Cau	0,30	12514	41713	2789,926
Le Chan	Ho Nam	0,35	14897	42562	2779,482
Le Chan	An Duong	0,21	9646	45933	2420,538
Le Chan	Du Hang Kenh	2,74	24817	9057	11081,165
Le Chan	Du Hang	0,30	13145	43816	2349,659
Le Chan	Dong Hai	0,42	13978	33281	4419,269
Le Chan	Niem Nghia	0,46	10953	23810	3251,496
Le Chan	Nghia Xa	0,65	11899	18306	3795,804
Le Chan	Vinh Niem	4,47	12152	2718	10635,602
Le Chan	Tran Nguyen Han	0,28	13898	49636	3321,102
Le Chan	Lam Son	0,49	11584	23640	3978,497
Ngo Quyen	May Chai	2,37	16769	7069	6834,730
Ngo Quyen	May To	1,50	14030	9353	7444,721
Ngo Quyen	Van My	1,09	17048	15640	6962,245
Ngo Quyen	Cau Tre	0,44	16972	38573	3473,768
Ngo Quyen	Lac Vien	0,40	12144	30360	2984,128
Ngo Quyen	Luong Khanh Thien	0,29	7845	27052	2832,856
Ngo Quyen	Gia Vien	0,26	11016	42369	2398,261
Ngo Quyen	Dong Khe	0,18	11862	65900	6969,058
Ngo Quyen	Cau Dat	0,15	9931	66207	2123,058
Ngo Quyen	Le Loi	0,23	8976	39026	2287,374
Ngo Quyen	Lach Tray	0,64	10041	15689	6356,556
Ngo Quyen	Dang Giang	1,78	13783	7743	8376,181
Ngo Quyen	Dong Quoc Binh	0,24	9071	37796	2204,186

2.2.3.4. Pollution monitoring data

Four air quality monitoring campaigns at 23 locations in HaiPhong were performed in March, June, September and December 2007 by the research team using a passive sampling method. Measurements were undertaken at different locations along the road network, including intersections and roadsides. Among them, four measuring points were chosen as background points, where traffic-related pollution is very low (Table 7 and Figure 11). Air pollutants measured include: SO_2 (mg/m^3), NOx (mg/m^3), CO (mg/m^3), TSP ($\mu g/m^3$), PM_{10} ($\mu g/m^3$), O_3 ($\mu g/m^3$), HC (mg/m^3). SO_2, NO_2, CO, TSP, PM_{10} samples were collected between 7:00 and 9:00 a.m daily. O_3 and HC samples were collected between 11:30 to 14:00 daily. All samples were collected using passive sampling method. The measured data are used to calibrate the dispersion model.

Table 7. Measurement locations

Code	Description	Coordinates	
A1	Intersection Lạch Tray – Ngô Gia Tự	N: 20.82966	E: 106.69934
A2	Intersection Lạch Tray – Nguyễn Văn Linh – Nguyễn Bỉnh Khiêm	N: 20.84065	E: 106.69410
A3	Intersection Cầu Đất – Lê Lợi – Tô Hiệu	N: 20.85210	E: 106.68622
A5	Intersection Lê Hồng Phong – Nguyễn Bỉnh Khiêm	N: 20.84375	E: 106.70889
A7	Intersection Nguyễn Đức Cảnh – Cầu Đất – Trần Phú	N: 20.85613	E: 106.68179
A8	Intersection Quang Trung – Trần Hưng Đạo	N: 20.85691	E: 106.86158
A9	Intersection Tôn Đức Thắng – TrầnNguyênHãn – TôHiệu	N: 20.84968	E: 106.67114
A10	Niem bridge: TRầnNguyênHãn – NguyễnVănLinh	N: 20.83868	E: 106.66489
A11	Intersection TônĐứcThắng – NguyễnVănLinh		
A12	Intersection NguyễnĐứcCảnh – TrầnNguyênHãn		
A13	Intersection CùChínhLan – Nguyễn Tri Phương	N: 20.86290	E: 106.67956
A14	Intersection Lê Lai – LêThánhTông		
A15	Intersection BạchĐằng – HùngVương – HồngBàng	N: 20.86216	E: 106.66270

Code	Description	Coordinates	
A16	Intersection LêDuẩn-TrầnNhânTông-TrườngChinh	N: 20.82190	E: 106.64888
A17	Intersection TrầnNhânTông – PhanĐăngLưu-TrầnThànhNgọ	N: 20.80316	E: 106.62553
A18	Intersection ĐườngHàNội – Xi MăngĐen	N: 20.86323	E: 106.66270
A19	Intersection NguyễnBỉnhKhiêm – LêThánhTông		
P1	Kim Đồng park	N: 20.85992	E: 106.68735
P2	Nguyễn Du park	N: 20.85896	E: 106.68735
P3	NguyễnBỉnhKhiêm park	N: 20.85780	E: 106.68496
P4	NguyễnVănTrỗi park	N: 20.85686	E: 106.68294
P5	LêChân park	N: 20.85603	E: 106.67957
C1	Lach Tray stadium	N: 20.85092	E: 106.68786

2.2.3.5. Meteorological data

Meteorological data (wind speed, direction, mixing height) are part of a worldwide dataset provided by the World Meteorological Organisation using data from NOAA in the USA. These are default data of the model. It was not possible to use the meteorological data provided by the Hai Phong based monitoring station due to technical problems during the study period while data from other stations in Vietnam could not be obtained timely for the research.

2.2.4. Model application

The results of the transport model (number of segments, traffic data, etc.) were exported in a GIS database and were used as inputs for the emissions model. For each scenario (*see following section*), the numbers of vehicles by type and by link in the entire Hai Phong road network are included. Emissions are calculated for each grid-cell (200 m x 200 m). To this end, the road network (links) was overlaid with the grid. The road-grid coverage is a map of the road network where each road link has been broken up into line segments by the grid-cells. Emissions in each line segment were calculated.

Emissions of the roads falling in each grid-cell were summed up and assigned as volume emissions to the cell itself.

The ***emissions model*** used the following parameters: Emission factors (E_f) for free-flowing conditions (g/km) were obtained from Sivacoumar and Thanasekaran (2000). For free-flowing conditions, $\mathbf{E_f}$ of PM_{10} in g/km for cars and taxis was 0.27, 3.0 for trucks, buses and diesel vehicles, and 0.21 for the 2-wheelers.

For the ISC3ST ***dispersion model***, the initial lateral and vertical dimensions are equal to 93 (the distance between volume sources divided by 2.15) and 0.5, respectively. The ISC3ST dispersion model was used to estimate the concentration of air pollutants (PM_{10}; NOx; SO_2; CO) based on the traffic data (vehicle volume, types and density) using the emission model. The concentrations of air pollutants were modelled for two worst-case-scenarios: max value during 24 hours and max values for 1 year (365 days).

2.2.5. Scenario building for the Hai Phong case study

Transportation planning and management aims to matching transportation supply with travel demand, which supposes transportation infrastructure. An in-depth understanding of the existing travel patterns is necessary for identifying and analyzing existing traffic-related problems as well as forecasting / predicting transport needs. The prediction of future travel needs is essential for long-term transportation planning which includes developing strategies for future transport. These strategies address land use, pricing, and expansion of highways, roads and transit services.

The transportation model used in this study identifies and quantifies all major mobility patterns and traffic flows in Hai Phong City. The model provides accurate estimates of the current and projected traffic conditions and patterns. Four scenarios were developed to this end. The second objective of this model is applying evaluation criteria and qualifying the outputs and suggested measures for the study area. These output data are useful for the Integrated Mobility Plan for the city of Hai Phong. The first objective requires a valid model, while the second step includes also preferences of decision-makers and transportation users.

The scenarios that have been developed for the city of Hai Phong are based on a basic scenario, called "average scenario" in the following sections. This is built on the traffic situation in the city in 2007, the data that has been collected from the mobility questionnaires and the current supply capabilities of the existing road network. The other three scenarios, including two maximum scenarios and a minimum scenario, take into account socio-economic growth rates. The maximum scenarios are built based on data described in the Master Plan of Hai Phong City towards 2010 and 2020. The minimum scenario was built based on the assumption of reducing of growth rates (Table 8).

Table 8. Description of transport scenarios developed for this research

Minimum Scenario	Average Scenario (Base scenario)	Maximum Scenario 1	Maximum Scenario 2
30% reduction of today’s growth rates. 365 days.	Current situation. 365 days.	Projection of current situation based on Master Plan’s growth rates. 365 days.	Projection of current situation based on Master Plan’s growth rates and shift among modes as follows: -5% motorcycle, -5% bicycle, +10% car. 365 days.

While the average scenario represents an estimate of the actual mobility patterns in Hai Phong, the other scenarios are policy dependent. In the minimum scenario, a reduction of the actual growth rate of (-)30% is assumed, while the first maximum scenario uses the growth rates assumed in the Master Plan of the Hai Phong city are achieved: (+)30% growth for all means of transport, while the capacity and the infrastructure of the transportation network will remain the same as today. The second maximum scenario relies on the same assumptions as the first maximum scenario with an additional shift of transport mode in favour of private cars by 10 percent and a reduction of 5 percent for both motorcycles and bicycles. For all four scenarios, the model was run for 365-day.

2.3. Health Impact Assessment

2.3.1. Health risk characterisation

2.3.1.1. Health risks of air pollutants

Risk characterisation in this study is merely based on the published literature review. Particulate matter was selected as the indicator pollutant in this assessment based on its prominent role in recent literature. Many studies found that the level of PM10 is strongly associated with the rate of death from all causes and from cardiovascular and respiratory illnesses while the evidences are weaker to link ozone and the other pollutants to the mortality rate (Sarnat, Schwartz, and Suh 2001; WHO 2003; C A Pope, Bates, and Raizenne 1995; C Arden Pope, Ezzati, and Dockery 2009; Feng and Yang 2012). WHO (2003) adopted a recommendation to use fine particulate matter ($PM_{2.5}$), as the indicator for health effects induced by particulate pollution such as increased risk of mortality in Europe, to supplement the commonly used PM_{10} (which includes both fine and coarse particles).

A health outcome inventory of the situation in the field using a health survey questionnaire is established. A health outcome is a health situation, such as an illness, cases of hospitalisation or death, resulting (the outcome) from exposure to air pollution. The following health outcomes were finally selected based on the available data:

- Total premature mortality, excluding accidents and violent deaths.
- Cardiac hospital admissions due to PM_{10}.
- Hospital admissions due to respiratory diseases due to PM_{10}.
- Restricted Activity Day due to $PM_{2.5}$.
- Hospital admissions for ischemic heart disease and hypertension due to noise pollution

2.3.1.2. Respiratory and circulatory health outcomes

In addition to the literature screening, health outcomes prevalence for respiratory and circulatory diseases have been supplemented in Hai Phong using the records provided by the Department of Health of Hai Phong (which merge the data submitted by all public hospitals in the city), for the years 2005, 2006 and the first 6 months of 2007 were collected as part of the risk characterisation process. Similar data for Ha Noi could not be obtained.

Health outcomes are classified according to the International Classification of Diseases version 10 (ICD-10) of the World Health Organization (WHO 2007). According to the Hai Phong Department of Health, the life expectancy in Hai Phong is 74.6 years. In this way Hai Phong ranks amongst the provinces with the highest life expectancy in Vietnam. The national life expectancy is 71.3 years and that of the Red River Delta is 73.3 years (Hai Phong Department of Health 2007).

The most common respiratory diseases are acute upper respiratory tract infections (acute pharyngitis, acute tonsillitis, acute laryngitis and tracheitis, other acute upper respiratory infections), influenza and pneumonia, other acute lower respiratory infections (acute bronchitis and bronchiolitis), diseases of the upper respiratory tract (vasomotor and allergic rhinitis, chronic rhinitis, nasopharyngitis and pharyngitis, other diseases of upper respiratory tract), chronic lower respiratory diseases (emphysema, chronic asthmatic bronchitis (obstructive)) and lung diseases due to external agents. 254,995 hospital admissions were recorded for diseases of the respiratory system, and most of them related to the upper respiratory tracts. Among them, 79,892 were due to acute pharyngitis and acute tonsillitis; 27,429 were due to acute laryngitis and tracheitis; and 23,821 cases of other acute upper respiratory infections were recorded. For the lower respiratory tract, pneumonia alone accounted for 21,144 cases.

Among the diseases of the circulatory system, primary hypertension is the most common disease since 2003. It accounts for 39.66% of the total circulartory system admissions to hospitals in 2006.

2.3.1.3. Health survey

The third part of the risk characterization concerns a health survey in Hai Phong City. A 2-part questionnaire was developed to survey the health impacts that may be attributed to air pollution. The first part contains questions about the household as a whole while the second part concerns the individuals in the household, in which the respondent was asked about his/her medical/health history including the exposure to different sources of air pollution (including occupational sources and tobacco smoke), their health situation in the past 5 years and at present (last 2 weeks). The survey was performed during the period July and August 2007.

In total 1797 individuals from 501 households were interviewed (Table 9) using random sampling method. Out of these 1797 respondents, 881 are male (49%) and 915 are female (50.9%). Most of the respondents finished high-school (63.7%). Very few people have no education (47 out of 1797 persons or 2.6%). 65.2% of the respondents are married (1171 persons) and 32.7% are single (588 persons). A few are divorced or widowed.

Table 9. Summary of interviewed data

	Number of individuals	Number of households
N (valid)	1797	501
Missing	0	0

Most of people interviewed are over 30 year olds (61.8%) with the group from 30 to 60 year olds account for a majority (48.3% of total). Children under 15 accounts for 200 cases (Table 10).

Table 10. The age-groups of individuals participating in the household survey

Age group	Frequency	Percent	Valid percent	Cumulative Percent
<15 year-old	200	11.1	11.1	11.1
15 - 30 year old	487	27.1	27.1	38.2
30 - 60 year old	868	48.3	48.3	86.5
60+ year old	242	13.5	13.5	100.0
Total	1797	100.0	100.0	

Most of the people interviewed have lived in the area for more than 5 years. 28.5% lived in Hai Phong for over 25 years and only 14.7% have recently moved to the area (lived less than 5 years in Hai Phong) (Table 11).

Table 11. Number of people participating in the household survey, grouped by period living at the same address

Period	Frequency	Percent	Valid Percent	Cumulative Percent
< 5 years	264	14.7	14.7	14.7
5 - 15 years	525	29.2	29.2	43.9
15 - 25 years	495	27.5	27.5	71.5
25+ years	513	28.5	28.5	100.0
Total	1797	100.0	100.0	

Of the 501 households interviewed, 61.7% live near a main road (under 5 m from a main road). This equals 1212 people out of 1797 people interviewed. Only 7.4% (37 households) live further than 150 m from a main road (Table 12).

Table 12. Number of sampled households by the distance to the main road

Distance	Frequency	Percent	Valid Percent	Cumulative Percent
< 5m	309	61.7	61.7	61.7
5 – 19m	80	16.0	16.0	77.6
20 – 49m	25	5.0	5.0	82.6
50 – 99m	21	4.2	4.2	86.8
100 – 149m	29	5.8	5.8	92.6
150+ m	37	7.4	7.4	100.0
Total	501	100.0	100.0	

Table 13. Number of sampled people living at the same address grouped by duration

	Number of years living at current address					
	< 5	5 - 9	10 - 14	15 - 19	20 - 24	25+
Number of people	142.00	296.00	242.00	273.00	254.00	731.00

Most of the people interviewed live within 5 m from a main road. This reflects a reality in Hai Phong, and the same applies to other cities in Vietnam, where houses are most close to the street. Houses at the front are more expensive as they provide more opportunities for income gains (opening of shops, renting out, etc.).

Table 14. Number of people grouped by distance to a main road

	Distance to the main road					
	< 5 m	5 – 19	20 – 49	50 - 99	100 - 149	150+
Number of people	1212.00	306.00	100.00	70.00	105.00	145.00

78% of the people who live near a main road live there for more than 10 years (241 households - 1500 people) (Table 13 and Table 14).

2.3.2. Dose-response functions for HIA

2.3.2.1. PM_{10} and mortality

The epidemiological approach used in this study to calculate the health outcome related to PM_{10} follows a methodology that has been used before (Kunzli et al. 2000; S Medina et al. 2005; Fisher et al. 2002; Ruttan and Tyedmers 2007). In these studies, health outcome was calculated only for adult group over 30 years of age in the long term cohort study conducted by Dockery et al. (1993) that resulted in the dose-response association. Mortality in children and people younger than 30 years was not included in the study of long-term effects of particulate matters. The following formula calculating long-term impact of PM_{10} on mortality within the group over 30 years is used:

$$\mathbf{Po = Pe/(1+((RR-1)(E_{PM} - B_{PM})/10))}$$

where:

- Po = baseline mortality per 1,000 in the age group 30+, after deducting the air pollution effect (this will depend on the other variables)
- Pe = crude mortality rate per 1,000 in the age group 30+
- E_{PM} = PM_{10} exposure level in the area of interest
- B_{PM} = threshold PM_{10} exposure level for mortality effect. In this study, we assumed the threshold for PM_{10} at 7.5, as proposed by Fisher et al. (2002).

- RR = epidemiologically derived relative risk for a 10 µg/m^3 increment of PM$_{10}$, assuming a linear dose-response relationship above the threshold (B) for the age group 30+. For this study, the RR suggested by Kunzli et al. (2000) was used (4.3%) (Table 15).

The increased mortality is calculated using the formula:

$$\mathbf{D_{PM} = Po * (RR - 1)}$$

Where D$_{PM}$ is the number of additional deaths per 1,000 people in the age group 30+ for a 10 µg/m^3. The number of deaths due to PM$_{10}$ is calculated by the formula:

$$\mathbf{N_{PM} = D_{PM} * P_{30+} * (E_{PM} - B_{PM})/10}$$

Table 15. Risk estimate used in Kunzli et al. (2000)

Health outcome	Relative risk (RR) [a]	95% CL [b]
Total mortality (adults >30 years, excluding violent deaths)	1.043	1.026 - 1.061
[a] Relative risk associated with a 10 µg/m^3 increase in PM$_{10}$ [b] 95% confidence level		

2.3.2.2. Health impact of PM$_{10}$ and PM$_{2.5}$ on morbidity

Two main categories of morbidity effects of PM$_{10}$ have been described: chronic obstructive pulmonary diseases (COPD) and respiratory admissions to hospital (Fisher *et al.*, 2002).

COPD can include bronchitis (J20), chronic bronchitis (J21), emphysema (J43), brochiectasis (J47), extrinsic allegoric alveolitis (J67), and chronic airways obstruction (J44). These are identified by ICD10 Chapter X (J00-J99) - Diseases of respiratory system - of WHO (2007b). In 2006, these occurred in Hai Phong in 28.1 per 1,000 inhabitants of all ages. This is 13.6 times higher than the rate in Christchurch (New Zealand) where the average rate is 2.06 per 1,000 inhabitants of all ages.

To calculate PM$_{10}$-related morbidity the rate all over Hai Phong will be applied to the five urban districts, although the rates in the urban districts might be higher. The annual increased admission rate for COPD used is 21.4% per 10 µg/m^3 of PM$_{10}$ as suggested by the WHO.

Respiratory admissions to the hospital are calculated based on the rates adopted by WHO for respiratory hospital admissions for all ages (1%) and cardiovascular hospital admissions for all ages (1.3%) for a 10 µg/m^3 increase in annual PM$_{10}$. The increased rate functions are applied to annual hospital admissions, based on those obtained from the Department of Public Health of Hai Phong (2007).

For PM$_{2.5}$, the morbidity effects are calculated based on the number of restricted-activity days (Fisher et al. 2007). The dose-response relationship used is 9.1 cases per 100 persons per 1 µg/m^3 annual PM$_{2.5}$. As data on PM$_{2.5}$ is not readily available for Hai Phong, a fraction of 0.7 of PM$_{10}$ was used (S Medina et al. 2005) estimating the PM$_{2.5}$ concentrations.

2.3.2.3. Health impact of benzene on mortality and morbidity

The cancer risk from exposure to benzene was discussed in chapter 1. The World Health Organisation calculated a range of unit risks for lifetime exposure to 1 µg/m^3 of benzene of 4.4 to 7.5 per million people, and proposes that the geometric mean value of that range, 6.0 per million, should be used (WHO 2000).

Benzene has a well defined cancer risk and a zero threshold. The cancer risk is assessed using the inhalation unit risk (IUR), which is defined as the probability that a person develops leukaemia when exposed to 1 µg/m^3 of benzene during the average lifetime. The estimated number of cancer cases due to benzene exposure per annum is calculated using the following formula:

$$\mathbf{N_{Benzene} = P_{exp} \times (RR \times E)/L}$$

where:

- $N_{Benzene}$ = number of cancer cases per annum
- P_{exp} = Number of people exposed to benzene
- RR = Lifetime risk estimate, equal to 6.0 per million people, ranging from 4.4 to 7.5
- E = estimated longterm-exposure (annual) (µg/m^3)
- L = average life expectancy (year)

2.3.2.4. Health impact of NO_2

Health impacts of NO_2 can be calculated using dose-response functions from international studies which estimate the annual number of deaths and hospital admissions attributable to each pollutant. The dose-response functions for NO_2 are presented in Table 16.

Table 16. Relative Risk (RR) figures for NO_2 (acute hospital admission only)

Pollutant	Health outcome	Percent increase in daily health outcome associated with 1 μg/m^3 increase in pollutant	Reference
NO_2 24-hr average	Respiratory admissions (+65yrs)	0.30 (0.02 – 0.58)	Department of Environment of Perth (Australia) 2003
NO_2 24hr-avergae	Cardiovascular admissions	0.15 (0.01 – 0.29)	Department of Environment of Perth (Australia) 2003

The short-term morbidity was calculated using the daily dose-response function as suggested by Fisher et al. (2007). The annual number of hospital admissions attributed to the pollutant NO_2 for 2007 was calculated as follows:

$$\mathbf{Nr= (DR/100) \times H \times Sum_{365} (Ei - B)}$$

Where:

- Nr = annual number of respiratory hospital admissions attributed to NO_2
- DR = percentage increase in daily hospital admissions per 1μg/m^3 increase in pollutant
- H = baseline average number of hospital admission per day in 2006
- Ei = pollution level for each day in 2007
- B = threshold pollutant level at which health effects occur
- Sum = Summation over 365 days

Table 17. Relative Risk (RR) figures: mortality

Pollutant	Health outcome	Percentage increase in annual mortality associated with 1 μg/m^3 increase in pollutant	Reference
NO_2 annual average	Non-external cause mortality	0.013 (0.011 – 0.015)	Scoggins et al. 2004
NO_2 annual average	Circulatory & respiratory mortality	0.018 (0.015 – 0.021)	Scoggins et al. 2004

The long-term mortality (annual average) was calculated using the function as suggested by Fisher et al. (2007) as follows:

$$\mathbf{N_{NO2} = (DR/100) \times (A-B) \times C}$$

where:

- N_{NO2} = annual number of respiratory hospital admissions attributed to NO_2
- DR = percentage increase in annual hospital admissions per 1 μg/m3 increase in pollutant
- A = annual average NO_2 concentrations
- B = threshold level at which health effects occur
- C = baseline annual average number of deaths

However, it should be noted that there is uncertainty over the degree to which a single pollutant contributes to the complex health impacts caused by a mix of many pollutants. To avoid double counting of adverse health effects related to air pollution, usually only one pollutant is chosen to quantify health outcomes. Particulate matter is usually considered the single pollutant. Therefore, adverse health effects of NO_2 were not included and not added to the total health impacts of air pollution in this study.

2.3.2.5. Health impact of noise

The four main impacts of environmental noise on human health (WHO, 2004) are severe annoyance (SA), highly sleep disturbance (HSD), hypertension (HT) and ischaemic heart disease (IHD). The “Disability Adjusted Life Year” (DALY) was used as the indicator for the health impacts of noise (Prüss-Üstün et al. 2003). The DALY was introduced by the World Bank and World Health Organisation (WHO) studying the “Global burden of disease” (Anand and Hanson 1997).

DALY is calculated as follow:

$$\mathbf{DALY = YLL + YLD}$$

where

- YLL is the life years lost due to premature mortality
- YLL = 'number of deaths' x 'life expectancy at death'
- YLD is the number of years lived with disability.
- YLD = 'number of people affected' x 'average duration of response x severity'

Assuming that people will be annoyed throughout the year (Krzyzanowski, Kuna-Dibbert, and Schneider 2005), the ***duration*** of the response is set at 1 for all health outcomes studied in this report. This parameter is also confirmed by other studies (de Hollander et al. 1999; Torfs 2003; Knol et al. 2005; Stassen, Collier, and Torfs 2008). The noise level used was L_{Aeq}-24hr[4], calculated as an average of 34 measuring points. The number of people exposed to traffic noise was calculated on this data using GIS overlay.

The ***severity*** is referred to the disability weight, which is disease specific and based on public health and medical experts’ judgments using "Person Trade-Off". The severity ranges between 0 (perfect health) and 1 (death).

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[4] Equivalent Continuous Level (dBA)

2.2.3.5.1. Severe Annoyance and Highly Sleep Disturbance

The *severity* of "severe annoyance" and "highly sleep disturbance" was set at 0.01, as suggested by de Hollander et al. (1999).

For severe annoyance, the uncertainty interval is 0.002 to 0.12 and for highly sleep disturbance the uncertainty interval is 0.002 to 0.10 as reported by Stassen, Collier, and Torfs (2008) who followed recommendations of Botteldooren (personnal communication of Stassen, Collier, and Torfs (2008)) for the maximum value and Kempen (cited in Knol et al. 2005) for the minimum value.

In studies on Severe Annoyance and Highly Sleep Disturbance, the YLL was discounted as this element was used mainly to estimate the loss of life expectancy due to the cardiovascular outcomes, such as noise-induced hypertension, which leads to mortality that relates to cardiovascular disease (WHO Regional Office for Europe 2007).

To calculate the DALY of severe annoyance (SA), percentage of the population affected by traffic noise was calculated using the dose-response function suggested by Miedema and Oudshoorn (2001):

$$\%SA = 9.868 \times 10^{-4} (L_{DEN}-42)^3 - 1.436 \times 10^{-2} (L_{DEN}-42)^2 + 0.5118 (L_{DEN}-42)$$

where L_{DEN} is the day-evening-night level of noise.

To calculate the DALY of highly sleep disturbance (HSD), the percentage of the population affected by traffic noise was calculated using the dose-response function suggested by Miedema and Oudshoorn (2001):

$$\%HSD = 20.8 - 1.05\, L_{night} + 0.01486\, L_{night}^2$$

where L_{night} is the level of noise at night.

In this study, because noise data in Vietnam are only available as L_{Aeq} values, therefore instead of L_{DEN} and L_{night}, L_{Aeq} was used. As was reported by Babisch (2006) quoting other studies (Evans et al. 2001; Rylander et al.), the day noise level can be used as an approximate relative measure of the night level in studies in which the relative effect of road traffic noise is assessed. This seems to be also justified because existing noise regulations usually consider a 10 dB(A) difference between the day and the night (Babisch 2006).

2.2.3.5.2. Hypertension and Ischaemic Heart Disease

The *severity* of “Hypertension” (HT) was set at 0.352, as suggested by Mathers, Vos, and Stevenson (1999) and the *severity* of “Ischaemic Heart Disease” (IHD) was set at 0.35 as suggested by de Hollander et al. (1999). The effects will start from a threshold as reported in Table 18.

Table 18. Long-term effects of exposure to environmental noise, and information on their observation threshold

Effect	Observation threshold			References
	Metric	Value in dB(A)	Indoors/ outdoors	
Hypertension				
Ischaemic hearts disease	Lden	70	out	HCN 1994
Annoyance	Lden	for % SA[#] 42	out	Miedema and Oudshoorn 2001
Sleep disturbance				
Self-reported sleep disturbance	Lnight	for % HSD[§]< 45	out of the most exposed façade	Miedema and Oudshoorn 2001
Mood next day	LAeq, night	>60	out	HCN 1994
[#] SA – Severe annoyance [§] HSD - Highly Sleep Disturbed				

The Relative Risk (RR) for HT is 1.26 (1.14 to 1.39) for each increment of 5dB (A) (Knol et al. 2005). The $RR_{5dB(A)}$ for IHD is 1.09 (1.05 to 1.13). The RR for hypertension-based mortality is estimated to be 1.4 (1.2 to 1.6) (Van Kempen et al. 2003).

Prevalence of HT and IHD in Hai Phong was provided by the Hai Phong Department of Healtth (2007). Statistics on hospitalisation and outpatient cases was collected for Hypertensive diseases (ICD codes I10-I15) and Ischaemic heart diseases (ICD codes I20-I25).

The health endpoints linked to noise will be calculated using the following functions:

AR% = (RR-1) / RR * 100

PAR% = Pe/100 * (RR-1) / (Pe/100 * (RR-1) + 1) * 100

PAR = PAR% * Nd

where

- RR = Relative risk (odds ratios are estimates of the relative risk)
- Pe = Percentage of the population exposed
- Nd = Number of subjects with disease (disease occurrence or prevalence)
- AR% = the attributable fractions
- PAR% = the population attributable risk percentages
- PAR = the absolute numbers of affected subjects for each noise category with an interval of 5dB(A) above the threshold.

2.3.3. Exposure assessment

2.3.3.1. Exposure to particulate matters (PM_{10} and $PM_{2.5}$)

The number of people exposed to particulate pollution was calculated using GIS by overlaying concentration maps on population density map. Concentration maps result from the ISC3 model and contain the simulated concentration of PM_{10} for the whole study area. The concentration of PM_{10} is continuous (i.e. each point on the map corresponds to a concentration). Population density maps contain data on the area and population density of each zone. The exposed population was therefore calculated for each zone. The number of people exposed was also calculated for each level (or interval) of concentration.

The exposed population for PM_{10} was only calculated for the group older than 30 years old (Kunzli et al., 1999). The age pyramid for Vietnam was used to calculate the percentage of the group 30+ as part of the whole population.

The $PM_{2.5}$ concentrations were calculated for each zone based on PM_{10} concentrations and a conversion factor (S Medina et al. 2005).

2.3.3.2. Exposure to other air pollutants

It is assumed that the whole population of Hai Phong is exposed to other pollutants at the same level due to the lack of data for calculating exposure to different exposure levels. The annual (2007) average concentration of other pollutants was used.

2.3.3.3. Exposure to noise

Exposure to noise was calculated based on measurements done in 2007 for 32 streets in Hai Phong. LAeq values were reported. To calculate the health effects it was assumed that all people in Hai Phong were exposed to the same level of noise. A city-wide average was therefore used, which was calculated as the mean LAeq of all measured locations. The highest noise level was 97.8 dB(A) with a daily average of 74.4 dB(A). The average level of noise at 50 m from the streets was 69.3 dB(A) (Stijn Dhondt et al. 2011).

CHAPTER 3. HEALTH IMPACT ASSESSMENT FOR THE HAI PHONG CASE STUDY [5]

3.1. Introduction

In modern societies, transportation is an essential link between all economic sectors and industries. It provides access to markets, education, jobs, leisure, and other services. With modern societies rely more and more on transportation, its impacts the environment have become a pressing issue through degrading environmental quality (air, water, soil), changing land use and climate (Black 2003; Rodrigue et al. 2006). As the consequences, transportation also poses dangers on human health, ranging from injuries, annoyance, to cardiovascular and respiratory diseases, cancer. The effects are especially pronounced for vulnerable groups such as children and elderly people, people with prior cardio-vascular and respiratory health problems, and vulnerable road users (pedestrians and cyclists) (Cirera et al. 2001; Ballester 2005; Krzyzanowski et al. 2005; Moshammer et al. 2005; Nicolopoulou-Stamati et al. 2005; Roussou and Behrakis 2005; WHO 2000; WHO 2006a).

Transport is a major source of ground air pollution, especially in urban areas. In northern Europe, transport contributes nearly 100% of CO, 70% of NOx, and 40% of PM_{10} of the immission values (WHO 2000). The traffic-related fraction of PM_{10} amounts to 43% in Austria, 56% in France, and 53% in Switzerland (Kunzli et al. 2000). Motor vehicles are the largest source of PM_{10} emissions in most Asian cities (Faiz and Sturm 2000). Studies in New Delhi (India), Bangkok (Thailand), Beijing (China), Hong Kong, Manila (Philippines) and Jakarta (Indonesia) show a high contribution of vehicles to the concentrations of particulate matter, ranging from 40% to 80% (Cheng et al. 2007; Kan and Chen 2004; Sagar et al. 2007; Syahril et al. 2002; Walsh 2002).

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[5] This chapter is based on following papers:

Hieu, V. V., Quynh, L. X., Ho, P. N. and Hens, L., 2013. Application of GIS and modelling in health risk assessment for urban road mobility. Environ Sci Pollut Res (2013) 20:5138–5149.

Dhondt, S., Quynh, L. X., Hieu, V. V., and Hens, L., 2011. Environmental Health Impacts of Mobility and Transport in Hai Phong, Vietnam. Stoch Env Res Risk A 25 (3): 363–376.

Hieu, V. V., Quynh, L. X., Ho, P. N. and Hens, L., 2010. Health Impact Assessment for Traffic Pollution (PM) for Hai Phong City, Vietnam. Anthropology Today: Trends and Scope of Human Ecology 5: 67–76.

Studies on health impacts of air pollution have been carried out very early in Europe and the United States of America with more epidemiological studies performed during the late 1980s and the 1990s (Burnett et al. 1998; K Katsouyanni et al. 1997; Samet et al. 2000; Schwartz and Dockery 1992a; Schwartz and Dockery 1992b; Xu et al. 1994). Amongst all air pollutants, particles, in particular PM_{10}, have been the subject of epidemiological studies and, more recently, reviews of these studies. The studies, set up in various parts of the world with under different conditions consistently showed that 24-hour average concentrations of PM_{10} are related with daily mortality and daily hospital admissions (Anderson et al. 2004; Dab et al. 2001; Dockery et al. 1993; Fisher et al. 2007; Krewski et al. 2005; C A Pope, Bates, and Raizenne 1995; Zanobetti et al. 2002; WHO 2003). The conclusion is that the relationships between traffic-related PM pollution and the effects on health are both valid and causal.

Hai Phong is a coastal city of the Northern part of Vietnam. The city hosts the country's second largest port which is located right at its heart. The port of Hai Phong accommodates shipping needs for the northern part of Vietnam, the north of Laos and south-western provinces of China. Not surprisingly, mobility in Hai Phong is closely related to the port's activities. Hai Phong witnessed a very fast growth in mobility during the period 2002 - 2005. However, transport brings also environmental and health hazards. In Hai Phong, it is estimated that road transport accounts for an estimated 60% of the total emitted volume of nitrogen oxides and 50% that of carbon monoxides and 25% that of particulates with diesel engines are the main emitters (Hai Phong DOSTE 2003). The air quality in Hai Phong degraded continuously during the last 10 years. As the port of Hai Phong plans to increase its activities, the city prepared in 2005 a Development Plan with an outlook to 2020, in which large projects on transport infrastructure are foreseen to meet the increasing demand that results from the current and projected development. More transportation will lead to more environmental and health impacts, such as the increase of air pollution and noise, and more injuries, mortality and morbidity. This calls for a systematic analysis of the environmental and health aspects related with transport, so that necessary measures can be taken to protect the environment and human health.

This chapter presents the results of a health risk assessment that quantifies the mortality and the morbidity associated with particulate matter of transport. Health impact assessment (HIA) is used. This includes hazard identification, exposure analysis, dose-effect relationships and risk assessment. Modelling and GIS approaches allow estimating exposure to increase the accuracy of the procedure. This starts with using a transport model to forecast mobility flows in different parts of the city. The results of the transport model are integrated in an emission model, which allows calculating emissions at road level. The next step is a dispersion model where GIS tools are used to calculate concentrations of air pollutants on a continuous range and to display them on a concentration map. When overlaying the concentration map with the population density map, human exposure to pollution can be estimated. Finally, health effects are calculated based on dose-response functions using the quantified exposures and relative risks from the literature.

3.2. Materials and methods

A model integrating three sub-models in a Geographical Information System (GIS) framework was applied to assess health effects of various traffic scenarios, related emission and pollution for the urban area in Hai Phong. As shown in Figure 12, those three sub-models were integrated to simulate each sub-process involved.

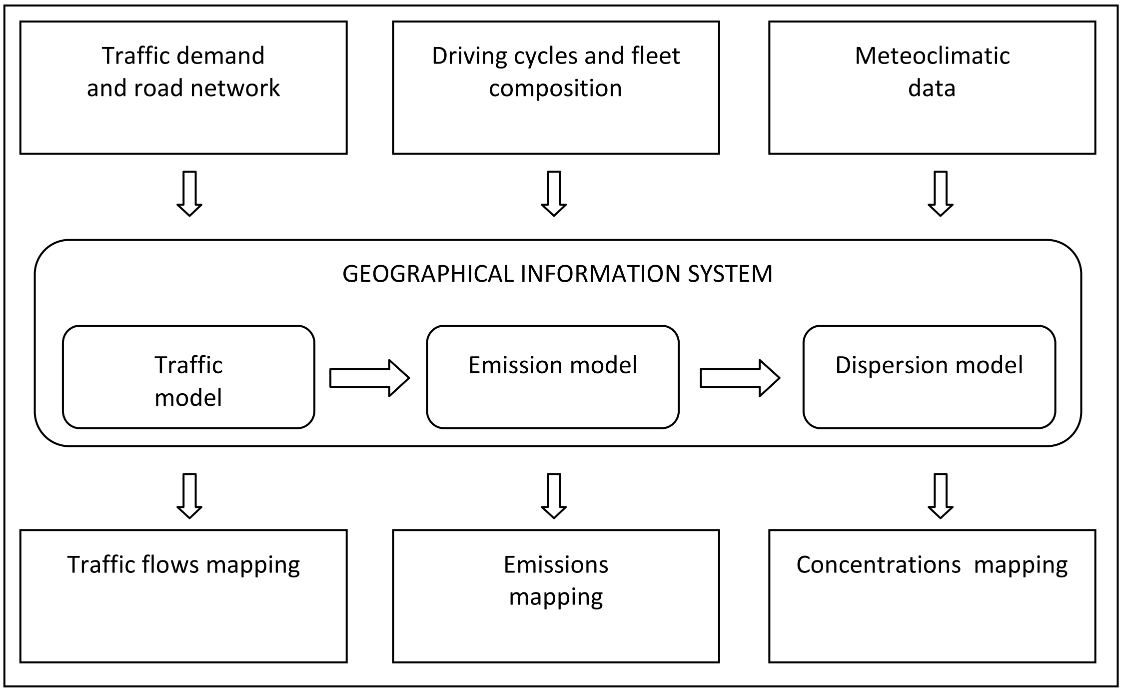

Figure 12. General structure of the integrated model system (Gualtieri et al. 1998)

The study area comprises 5 urban districts (52 communes in total) of Hai Phong City with a population of 598 thousand people and an average density of 3,522 people/km^2 in 2007. Ngo Quyen District is the densest area where in the most populated commune lived more than 66,000people/km^2. Hai An District is the sparsest one.

3.2.1. Transport scenarios

To estimate the emission of pollutants that affect human health, the VISUM ***traffic model***, a computer-aided transport planning programme, was applied to Hai Phong. The model allows to evaluate traffic loads on a road network, using O/D (Origin/Destination) matrix (for 4 modes: bus, bicycle, motorcycle, and car) and the description of the road graph. For each mode, parameters on occupancy rate, analysis period, maximum speed and type (public or private) were assigned. Hourly traffic fluxes are obtained from peak results using empirical coefficients estimated for the whole net. The model has significant data demands to define the activity and transportation systems. The primary need is data to define travel behaviour that is gathered via a household travel survey. The survey provides: (a) household and individual-level socio-economic data (typically including income and the number of household members, workers, and cars); (b) activity/travel data (typically including for each activity performed over a 24-hr period activity type, location, start time, and duration and, if travel was involved, mode, departure time, and arrival time; and (c) household vehicle data. Data from the survey is used to validate the representativeness of the sample, to develop and estimate trip generation, trip distribution, and mode choice models, and to conduct time-in-motion studies. In this study, 782 household questionnaires were collected, covering 0,31% of the total urban population. In addition, an observed traffic studies (counts and speeds) provide data needed for model validation.

The model runs on geo-referenced data of the road network and the administrative data of 52 urban communes of Hai Phong. The former include road name, ID and types (street, provincial road, national road) and are encoded into links (a section of the road network between two nodes) and nodes (determine the locations of street junctions). The latter includes information on district ID, the perimeter, area, population and density of each commune.

To estimate mobility development in the future, four scenarios have been considered: A minimum, a basic (or average), and two maximum scenarios (Ziliaskopoulos and Mitsakis 2008). The basic scenario (Scenario 2) builds on the traffic conditions in 2007 of the city, the data that has been collected from mobility questionnaires and the current supply capabilities of the road network. The other three scenarios are policy dependent. The maximum scenarios are based on socio-economic growth rates as described in the Master Plan of the city (Hai Phong PC 2006). The first maximum scenario (Scenario 3) predicts that the growth rates assumed in the Master Plan of the Hai Phong City are achieved. This coincides with a 30% growth of all means of transport, while the capacity and the infrastructure of the transportation network remains constant. This is because most of the new infrastructures will be outside the centre, such as new ring roads and bridges. Also, their details (locations, technical specifications) are not provided in the master plan to allow modelling future travel demand. The second maximum scenario (Scenario 4) is based on the same assumptions as the first maximum scenario, with an additional shift of mode share (10% increase in private cars, and a reduction of 5% of motorcycles and bicycles). This scenario is considered as realistic for Hai Phong in 2020. For the minimum scenario (Scenario 1), a 30% reduction of the existing traffic was assumed. In total, 16 Origin-Destination matrices have been computed.

Finally, the model was validated by comparing the modelling results for the basic scenario and the actual traffic count at 20 locations in Hai Phong (14 within the study area and 6 outside). At each location, traffic filming was done three times a day (morning, afternoon and night), each film segment lasts 20 minutes. Traffic was then reviewed through the film segments to count the number of vehicles for each of the four vehicular groups studied. The following table (Table 19) represents the differences of the model outputs for the base case scenario (scenario 2) and the actual observed traffic counts for 14 locations within the modeling area in the city of Hai Phong.

Table 19. Comparison of modelled results with traffic count data

Measuring station ID	Counted (Average Total Vehicles per 20 minutes)	Model output (Average Total Vehicles per 20 minutes)	Difference	Difference (%)
1	588	553	35	6,3%
3	584	601	-17	-2,8%
4	151	160	-9	-5,6%
5	1493	1430	63	4,4%
9	385	393	-8	-2,0%
10	147	151	-4	-2,6%
11	2072	2009	63	3,1%
12	662	669	-7	-1,0%
13	337	351	-14	-4,0%
14	409	422	-13	-3,1%
17	1457	1515	-58	-3,8%
18	1445	1469	-24	-1,6%
19	618	631	-13	-2,1%
20	1479	1426	53	3,7%

The comparison shows that the model produces reliable results, which correspond well with the traffic count data within a 6% difference.

3.2.2. Emission and dispersion of pollutants

The results of the transport model were exported into a GIS database and were used as inputs for the ***emissions model***. For each scenario, the numbers of different types of vehicles (except bicycles) per link in the entire Hai Phong urban road network were included. An emissions model has been developed on the basis of the results shown by Borrego et al. (2003). The formula used to determine the emissions per link is:

$$E = \sum_i V_i L E_f$$

Where **E** is the total emissions per link (g/s); ***i*** is the vehicle type; V_i is the volume per second of vehicle type *i* along the link; ***L*** is the length of the link (km); E_f is an emission factor of vehicle type *i* (g/km). Emission factors (E_f) for free-flowing conditions (g/km) were obtained from NEERI (Sivacoumar and Thanasekaran 2000) based on the fact that NEERI's study was based on the Indian vehicle fleets which are similar to the ones in Hai Phong in term of vehicle compositions, engine types and ages. For free-flowing conditions, E_f of PM_{10} in g/km for cars and taxis was 0.27, 3.0 for trucks, buses and diesel vehicles, and 0.21 for the 2-wheelers.

Aggregated emissions were calculated on a grid-cell 200mx200m as volumes sources so that the data can be imported to the dispersion model later. To calculate the emissions, the road-grid coverage was established by overlaying the link database with the grid-cell (200 m x 200 m) coverage. The road-grid coverage is a map of the road network where each road link has been broken up in line segments based on the grid-cells the links run through. Emissions along each line segment were calculated. Emissions in each cell were summed up over the roads and assigned as volume emissions to the cell itself. As a result, the emissions of the road network were split over a regular grid of 200 x 200 m volume sources.

A ***dispersion model*** was used to estimate the distribution of air pollutants. The ISC3ST was used. It is the third version of the Industrial Source Complex short-term model, called ISC3ST. The basis of the ISC3ST model is the straight-line, steady-state Gaussian plume equation. The ISC3ST is a multi-source dispersion model for point area, volume and open pit sources. The volume sources, as an output of the emissions model, were transferred to ISC3ST and can then be modelled and presented as line sources (USEPA 1995).

The ISC3ST was selected because it has been widely used and validated in studies on traffic air pollution in urban areas and EIAs for transport projects in Vietnam (Hoang 2008). Other available line sources models such as CALINE3, CALINE4 and HYROAD are limited to a maximum of 20 links for each single run, therefore, they are not applicable for a complicated road network like Hai Phong with more than 1700 links. Moreover, ISC3ST's data requirements fit with the data availability in Hai Phong. The ISC3ST uses daily data for traffic data (vehicle volume, types and density of traffic) and meteorological data (wind direction, velocity and mixing height). Meteorological data for 2003 were collected using a fix automated rooftop station at the Institute of Marine Environment and Resources in Hai Phong.

3.2.3. Estimation of health effects

The impacts of air pollutants on public health were estimated using a health risk assessment, which entails 4 steps: hazard identification, dose-response assessment, exposure assessment and risk quantification.

Hazard identification was based on a literature review. Particulate matter was selected as the indicator pollutant in this assessment, as suggested by Kunzli et al. (1999). Health impacts related to transport are reviewed to establish links between health outcomes and transport activities. Finally, total premature mortality (excluding accidents and violent deaths), cardiac hospital admissions due to PM_{10}, hospital admissions due to respiratory diseases due to PM_{10}, and number of Restricted Activity Days due to $PM_{2.5}$ were selected.

Dose-Response functions were based on epidemiological dose-response functions established by studies on health impact of PM_{10} and $PM_{2.5}$ on mortality and morbidity. The formula (Kunzli et al. 1999) to calculate the **mortality** resulting from long-term exposure to PM_{10} is:

$$Po = Pe/(1 + ((RR - 1)(E_{PM} - B_{PM})/10))$$

Where **Po** is the baseline mortality per 1,000 in the age group 30+, after deducting the air pollution effect (this will depend on the other variables); **Pe** is the crude mortality rate per 1,000 in the age group 30+; $\mathbf{E_{PM}}$ is the PM_{10} exposure level in the area of interest (in this study, data is from the model as described above); $\mathbf{B_{PM}}$ is the threshold PM_{10} exposure level for mortality effect (in this study, we assumed the threshold for PM_{10} at 7.5 (μg /m^3), as proposed by Fisher et al. (2007)); **RR** is the epidemiologically derived relative risk for a 10$\mu g/m^3$ increment of PM_{10}, assuming a linear dose-response relationship above the threshold (B) for the age group 30+ (For this study, RR as suggested by Kunzli et al. (2000) was used (4.3%) with 95% confidence level ranges from 1.026 - 1.061).

The increased mortality is calculated using following formula: $D_{PM} = Po * (RR - 1)$ where $\mathbf{D_{PM}}$ is the number of additional deaths per 1,000 people in the age group 30+ ($\mathbf{P_{30+}}$) for an increase of 10$\mu g/m^3$. The age pyramid for Vietnam is used to calculate the percentage of this group in the population in Hai Phong. The number of deaths due to PM_{10} is calculated by the formula:

$$N_{PM} = D_{PM} * P_{30+} * ((E_{PM} – B_{PM})/10)$$

As for short-term exposure to pollution, two main **morbidity effects** of PM_{10} were considered: *chronic obstructive pulmonary diseases* (COPD) and *respiratory admissions to hospital* (Fisher et al. 2007). The annual increase in the admission rate for COPD is 21.4% per 10 $\mu g/m^3$ of PM_{10} (Dockery and Pope 1994). COPD as proposed by Fisher et al. (2002) include bronchitis (J20), chronic bronchitis (J21), emphysema (J43), bronchiectasis (J47), extrinsic allergic alveolitis (J67), and chronic airways obstruction (J44) (codes from WHO 2007). In 2006, the incidence rate in Hai Phong is 28.1 per 1,000 people of all ages. To calculate the morbidity related to PM_{10}, the overall rate in Hai Phong will be applied.

Respiratory admissions to hospitals are calculated based on the rates adopted by Krzyzanowski, Kuna-Dibbert, and Schneider (2005) for respiratory hospital admissions for all ages (1%) and cardiovascular hospital admissions for all ages (1.3%) for a 10 $\mu g/m^3$ annual increase in PM_{10}. The increased rates are applied to annual hospital admissions, based on hospital records obtained from the Hai Phong Department of Healtth (DoH) (2007) to estimate extra hospital admissions in 2020.

For $PM_{2.5}$, the morbidity effect is calculated as the *number of restricted-activity days* (Fisher et al. 2002). This parameter is an important measure of functional well-being. The definition of "restricted-activity days" is the average annual number of days a person experienced at least one of the following: (1) a bed day, during which a person stays in bed more than half a day because of illness or injury related to traffic; (2) a work-loss day, on which a currently employed person misses more than half a day from a job or business; (3) a school loss day, on which a student 5-17 years of age misses more than half a day from the school in which he or she was currently enrolled; or (4) a cut-down day, on which a person cuts down for more than half a day on things (s)he usually does. The dose-response relationship used is 9.1 cases per 100 persons per 1 $\mu g/m^3$ annual increase of $PM_{2.5}$. As data on $PM_{2.5}$ is not readily available for Hai Phong, a fraction of 0.7 of PM_{10} was used to estimate this exposure (S Medina et al. 2005).

Exposure assessment aims to quantify the number of people exposed to PM_{10} and $PM_{2.5}$. The exposed population was calculated using a GIS-based approach that includes data on area and population density of the 52 communes and modelled PM_{10} concentrations from dispersion model. $PM_{2.5}$ concentrations were calculated based on PM_{10} concentrations.

Exposed population for PM_{10} was calculated for the P_{30+} group by overlaying concentration map on population density map. The number of people exposed to each level of concentration was calculated.

3.3. Results

3.3.1. Exposure assessment

To assess exposure, the concentrations of PM_{10} were modelled for the 4 transport scenarios, each for 2 worst-cases: maximum value during 24 hours and maximum value for 1 year. This was based on the results of the transport model, which calculated the number of vehicles on the Hai Phong roads for each of the 4 modes of transport (bicycle, car, motorcycle and truck) and for each of the 4 scenarios. As the model produces only continuous concentrations (which mean each point on the map corresponds to a specific concentration) while the data on population density is only available at commune level, it is necessary to calculate an accumulated concentration of pollution at commune level to proceed with the exposure assessment. Table 20 presents the results of the ISC3 model that produces the mean, population-weighted concentrations of PM_{10} for each of the commune in Hai Phong City in each traffic scenario. The results show that, in 2007 at commune level (basic scenario - scenario 2), the mean annual concentrations of PM_{10} are not expected exceeding 30μg/m^3. The highest modelled concentrations are found at Hong Bang District: commune Pham Hong Thai (at 26.46 μg/m^3) and commune Phan Boi Chau (at 26.20 μg/m^3). The Hong Bang district is in the centre of the city and communes Pham Hong Thai and Phan Boi Chau are amongst the busiest communes with a dense street network.

Table 20. Modelled annual concentrations of PM_{10} for each communes
in Hai Phong City

Urban district	**Urban commune**	**Mean concentration (μg/m^3) (population weighted)**			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Hai An District	Cat Bi	5.24	7.59	10.61	10.65
Hai An District	Dang Hai	4.15	6.01	8.40	8.43
Hai An District	Dang Lam	4.56	6.60	9.24	9.27
Hai An District	Dong Hai	1.37	1.99	2.78	2.79
Hai An District	Nam Hai	1.68	2.44	3.41	3.42
Hai An District	Trang Cat	1.25	1.81	2.53	2.54
Hong Bang District	Ha Ly	13.02	18.87	26.39	26.48
Hong Bang District	Hoang Van Thu	12.22	17.71	24.78	24.86
Hong Bang District	Hung Vuong	3.80	5.51	7.71	7.74
Hong Bang District	Minh Khai	9.99	14.48	20.25	20.32
Hong Bang District	Pham Hong Thai	18.25	26.46	36.99	37.12
Hong Bang District	Phan Boi Chau	18.07	26.20	36.63	36.76

Urban district	**Urban commune**	**Mean concentration ($\mu g/m^3$) (population weighted)**			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Hong Bang District	Quan Toan	1.71	2.48	3.47	3.48
Hong Bang District	Quang Trung	13.15	19.06	26.66	26.75
Hong Bang District	So Dau	5.56	8.05	11.26	11.30
Hong Bang District	Thuong Ly	9.57	13.87	19.39	19.46
Hong Bang District	Trai Chuoi	12.75	18.48	25.85	25.94
Kien An District	Bac Son	10.42	15.11	21.13	21.20
Kien An District	Dong Hoa	12.26	17.76	24.84	24.93
Kien An District	Nam Son	7.77	11.26	15.75	15.80
Kien An District	Ngoc Son	4.74	6.87	9.61	9.64
Kien An District	Phu Lien	3.54	5.14	7.18	7.21
Kien An District	Quan Tru	13.59	19.69	27.54	27.63
Kien An District	Tran Thanh Ngo	7.85	11.37	15.91	15.96
Kien An District	Trang Minh	3.32	4.81	6.72	6.75
Kien An District	Van Dau	4.69	6.80	9.51	9.54
Le Chan District	An Bien	16.00	23.18	32.43	32.54
Le Chan District	An Duong	15.40	22.31	31.21	31.31
Le Chan District	Cat Dai	16.84	24.41	34.13	34.25
Le Chan District	Dong Hai	11.89	17.24	24.10	24.19
Le Chan District	Du Hang	14.88	21.57	30.17	30.27
Le Chan District	Du Hang Kenh	11.91	17.25	24.13	24.21
Le Chan District	Ho Nam	10.44	15.13	21.16	21.23
Le Chan District	Lam Son	14.33	20.77	29.05	29.15
Le Chan District	Nghia Xa	15.75	22.83	31.93	32.04

Urban district	**Urban commune**	**Mean concentration (μg/m³) (population weighted)**			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Le Chan District	Niem Nghia	15.54	22.51	31.50	31.60
Le Chan District	Trai Cau	13.61	19.72	27.58	27.68
Le Chan District	Tran Nguyen Han	16.63	24.09	33.70	33.81
Le Chan District	Vinh Niem	9.70	14.06	19.66	19.73
Ngo Quyen District	Cau Dat	8.93	12.94	18.11	18.17
Ngo Quyen District	Cau Tre	6.13	8.88	12.43	12.47
Ngo Quyen District	Dang Giang	8.22	11.91	16.66	16.72
Ngo Quyen District	Dong Khe	7.36	10.66	14.91	14.96
Ngo Quyen District	Dong Quoc Binh	10.80	15.66	21.89	21.97
Ngo Quyen District	Gia Vien	9.12	13.22	18.49	18.55
Ngo Quyen District	Lac Vien	7.29	10.57	14.78	14.83
Ngo Quyen District	Lach Tray	11.24	16.30	22.79	22.87
Ngo Quyen District	Le Loi	10.61	15.37	21.50	21.57
Ngo Quyen District	Luong Khanh Thien	11.88	17.22	24.08	24.17
Ngo Quyen District	May Chai	3.42	4.96	6.94	6.96
Ngo Quyen District	May To	8.04	11.65	16.30	16.35
Ngo Quyen District	Van My	4.07	5.90	8.25	8.28

Only a forecast of population growth at city level (and not at commune level) is available. Therefore the changes of the concentrations of PM_{10} depend only on the prediction of traffic scenarios as described in Chapter 2.

The concentrations were mapped using GIS. The concentration maps were then overlaid with the city maps, which contain data on the boundaries of districts and their population density.

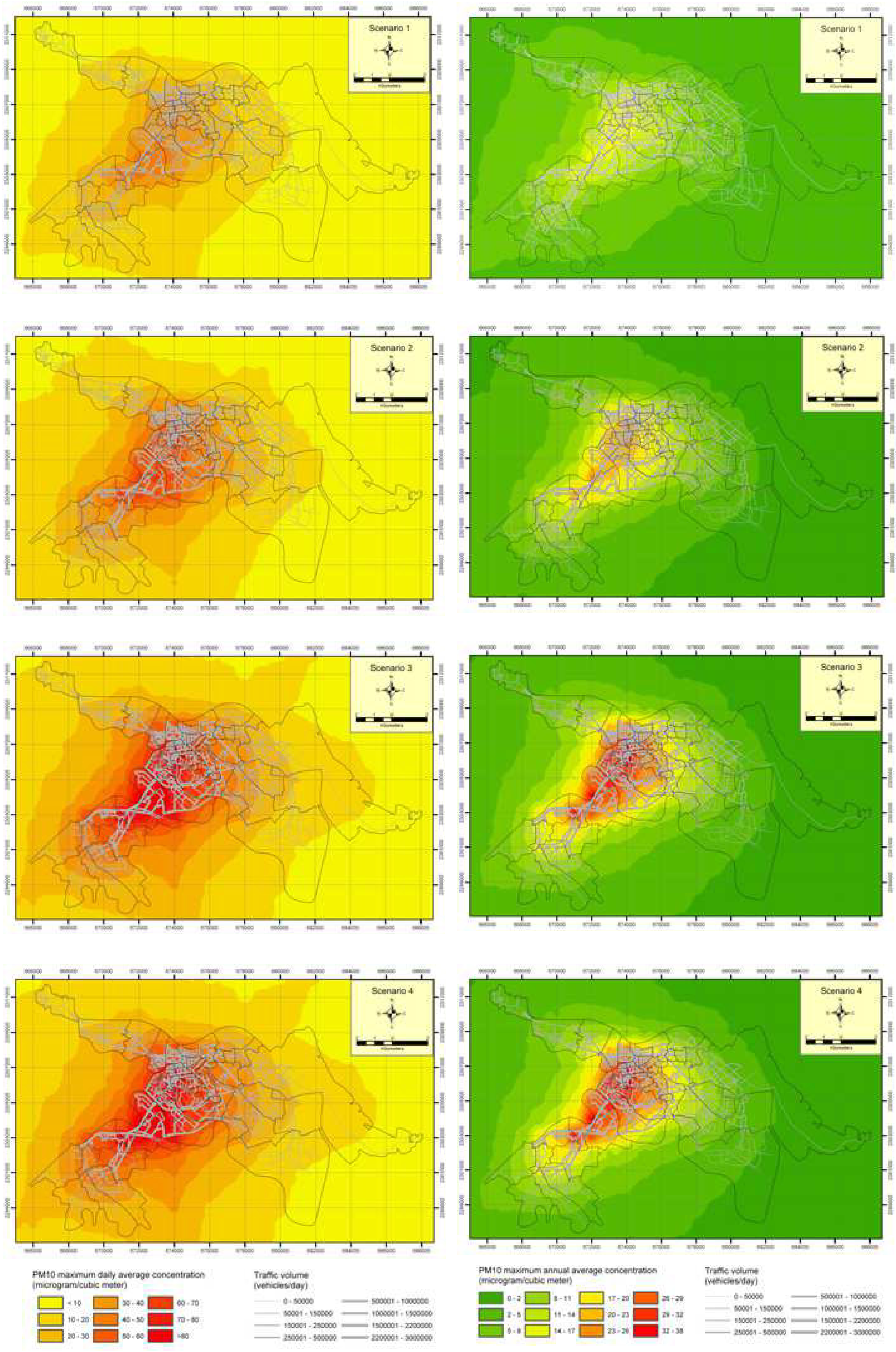

Figure 13. Modelled mean daily and annual concentration of PM_{10} for all scenarios

The maps in Figure 13 present the concentrations of PM_{10} by the steps. On the left are concentration maps for the max-24hours- mean, with the interval of 10 $\mu g/m^3$. On the right are concentration maps for the max-annual-mean with the interval of 3 $\mu g/m^3$. The maps also depict traffic volume of each street in each scenario. The streets are categorised in 8 groups with different traffic intensity.

The first minimum scenario (scenario 1), the 24h projection shows that most of the central city area will face daily concentrations of PM_{10} ranging between 20-40 $\mu g/m^3$. The annual (365days) projection shows that most of the central city area will be exposed a daily concentration of PM_{10} ranging between 17-20 $\mu g/m^3$.

The basic (or average) scenario (scenario 2) shows the actual situation in 2007. In this scenario, the 24hr calculation shows that the central city is heavily polluted with the average concentrations of PM_{10} ranging between 60-70 $\mu g/m^3$, much higher than standard. More importantly, there are road junctions where the average concentrations of PM_{10} reach maxima above 80 $\mu g/m^3$. The annual projections for the basic scenario show average concentrations of PM_{10} in the centre of the city ranging between 20-23 $\mu g/m^3$. Several road junctions face average concentrations of PM_{10} above 25 $\mu g/m^3$.

The first maximum scenario (scenario 3) reflects the socio economic situation as has been planned for Hai Phong for 2020. In this scenario, transport is projected to increase by 30% as compared to the situation in 2007. Consequently, the 24hr projections show a more heavily polluted central part of the city, with average concentrations of PM_{10} above 70 $\mu g/m^3$. The annual average is lower, with concentrations reaching 30 $\mu g/m^3$ for most of the central areas.

The second maximum scenario (scenario 4) reflects the socio economic situation as planned for Hai Phong for 2020. In this scenario, transport is projected to increase by 30% as compared to the situation in 2007. This is similar to the first maximum scenario but with a shift between the modes of transport. In this scenario, it is assumed that motorcycles and bicycles will lose their shares and will be replaced by private passenger cars, which reflects the actual development. It is estimated that motorcycles and bicycles will each lose -5% share and cars will gain +10%. In this scenario, the 24hr projections still show a heavily polluted central city similar to the first maximum scenario with average concentrations of PM_{10} above 70 μg/m^3. The annual average is lower, with concentrations around 35 μg/m^3 for most of the central areas, but higher than the first maximum scenario.

The maps show that the max-24hours-mean level of pollution is very high, with most of the centre of Hai Phong has high concentration of PM_{10}. In the current situation (scenario 2), most parts of the centre of Hai Phong have the PM_{10} concentrations in the range of 50 to 60 μg/m^3. The maximum annual mean of 20-23 μg/m^3 is less polluting (scenario 2).

In calculating exposure, only the population group over 30 year-old was taken into account using the methodology described under “Exposure Assessment”. This approach considers only average density of a commune and does not consider real-time location of people. In addition, the calculation of exposure is only for those exposed to concentrations higher above 7.5 μg/m^3. Most of the population in Hai Phong is exposed to the PM_{10} concentration ranging between 15μg/m^3 – 30 μg/m^3 (Table 21).

Table 21. Number of people over 30 years exposed to mean annual concentrations of PM_{10}

Level of exposure (μg/m3)	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
≤ 7.5	273,718	125,615	72,073	72,073
7.5 - 10.0	136,054	144,431	49,122	49,122
10.0 - 15.0	172,058	155,493	148,852	148,852
15.0 - 20.0	112,961	146,804	139,726	134,742
20.0 - 25.0	.	91,994	74,195	79,179
25.0 - 30.0	.	30,454	97,863	97,863
30.0 - 35.0	.	.	82,506	82,506
35.0 - 40.0	.	.	30,454	30,454
≥40.0	.	.	.	.

The shift from bicycles and motorbike to private cars produces little difference in term of contribution to PM concentration between scenarios 3 and 4. The changes will occur with more emissions at higher concentration between 20-25µg/m^3 when there is a shift from motorbikes to private cars. Therefore, more people will be exposed to the concentrations of PM$_{10}$ between 15-20µg/m^3 in scenario 3 while more people will be exposed to the concentrations of PM$_{10}$ between 20-25µg/m^3 in scenario 4. Based on the exposure maps, mean concentrations of PM$_{10}$ were calculated for each of the 52 communes in Hai Phong City (Table 22). Le Chan District has the highest number of communes with high concentration of PM$_{10}$.

Table 22. Modelled population-weighted mean concentration of PM$_{10}$ per urban commune for all scenarios

Urban district	**Urban commune**	**Mean concentration (µg/m^3) (population weighted)**			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Hai An District	Cat Bi	5,24	7,59	10,61	10,65
	Dang Hai	4,15	6,01	8,40	8,43
	Dang Lam	4,56	6,60	9,24	9,27
	Dong Hai	1,37	1,99	2,78	2,79
	Nam Hai	1,68	2,44	3,41	3,42
	Trang Cat	1,25	1,81	2,53	2,54
Hong Bang District	Ha Ly	13,02	18,87	26,39	26,48
	Hoang Van Thu	12,22	17,71	24,78	24,86
	Hung Vuong	3,80	5,51	7,71	7,74
	Minh Khai	9,99	14,48	20,25	20,32
	Pham Hong Thai	18,25	26,46	36,99	37,12
	Phan Boi Chau	18,07	26,20	36,63	36,76
	Quan Toan	1,71	2,48	3,47	3,48
	Quang Trung	13,15	19,06	26,66	26,75
	So Dau	5,56	8,05	11,26	11,30

Urban district	**Urban commune**	**Mean concentration ($\mu g/m^3$) (population weighted)**			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Thuong Ly	9,57	13,87	19,39	19,46
	Trai Chuoi	12,75	18,48	25,85	25,94
Kien An District	Bac Son	10,42	15,11	21,13	21,20
	Dong Hoa	12,26	17,76	24,84	24,93
	Nam Son	7,77	11,26	15,75	15,80
	Ngoc Son	4,74	6,87	9,61	9,64
	Phu Lien	3,54	5,14	7,18	7,21
	Quan Tru	13,59	19,69	27,54	27,63
	Tran Thanh Ngo	7,85	11,37	15,91	15,96
	Trang Minh	3,32	4,81	6,72	6,75
	Van Dau	4,69	6,80	9,51	9,54
Le Chan District	An Bien	16,00	23,18	32,43	32,54
	An Duong	15,40	22,31	31,21	31,31
	Cat Dai	16,84	24,41	34,13	34,25
	Dong Hai	11,89	17,24	24,10	24,19
	Du Hang	14,88	21,57	30,17	30,27
	Du Hang Kenh	11,91	17,25	24,13	24,21
	Ho Nam	10,44	15,13	21,16	21,23
	Lam Son	14,33	20,77	29,05	29,15
	Nghia Xa	15,75	22,83	31,93	32,04
	Niem Nghia	15,54	22,51	31,50	31,60
	Trai Cau	13,61	19,72	27,58	27,68
	Tran Nguyen Han	16,63	24,09	33,70	33,81
	Vinh Niem	9,70	14,06	19,66	19,73

Urban district	**Urban commune**	**Mean concentration ($\mu g/m^3$) (population weighted)**			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Ngo Quyen District	Cau Dat	8,93	12,94	18,11	18,17
	Cau Tre	6,13	8,88	12,43	12,47
	Dang Giang	8,22	11,91	16,66	16,72
	Dong Khe	7,36	10,66	14,91	14,96
	Dong Quoc Binh	10,80	15,66	21,89	21,97
	Gia Vien	9,12	13,22	18,49	18,55
	Lac Vien	7,29	10,57	14,78	14,83
	Lach Tray	11,24	16,30	22,79	22,87
	Le Loi	10,61	15,37	21,50	21,57
	Luong Khanh Thien	11,88	17,22	24,08	24,17
	May Chai	3,42	4,96	6,94	6,96
	May To	8,04	11,65	16,30	16,35
	Van My	4,07	5,90	8,25	8,28
Legends		Below 7,5 $\mu g/m^3$		7,5-15 $\mu g/m^3$	
		15-30 $\mu g/m^3$		Above 30 $\mu g/m^3$	

3.3.2. Estimation of health effects

3.3.2.1. Mortality due to PM_{10}

Detailed results on the increased mortality resulting from PM_{10} exposure for the group over 30 year olds are presented. The results are for the absolute mortality increases and not adjusted for year-life-lost. At the annual threshold of PM_{10} of 7.5 $\mu g/m^3$, the estimated number of persons dying by non-external causes that may be associated with traffic air pollution is 1,287 persons per year. Reducing the vehicle volume by 30%, a dramatic decline in health impact can be seen, with only 57 extra deaths due to PM_{10} pollution. The increase of 30% in the vehicle volume will lead to doubling the number of extra deaths. The absolute mortality per urban commune is summarised in Table 23.

Table 23. Absolute mortality due to PM_{10} per commune – by scenarios

Urban commune	**Urban district**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Cat Bi	Hai An	5.66	10.50	45.82	45.84
Dang Hai	Hai An	0.35	0.52	13.93	13.93
Dang Lam	Hai An	0.68	2.00	21.23	21.24
Dong Hai	Hai An	0.54	0.05	4.29	4.30
Nam Hai	Hai An	0.13	0	4.85	4.85
Trang Cat	Hai An	0.21	0	2.50	2.51
Ha Ly	Hong Bang	0.79	44.64	77.36	77.39
Hoang Van Thu	Hong Bang	0.58	14.97	27.38	27.39
Hung Vuong	Hong Bang	0.22	0.12	15.97	15.98
Minh Khai	Hong Bang	0.51	12.36	27.04	27.05
Pham Hong Thai	Hong Bang	0.84	20.10	29.57	29.58
Phan Boi Chau	Hong Bang	0.83	37.94	56.04	56.07
Quan Toan	Hong Bang	0.03	0	6.37	6.37
Quang Trung	Hong Bang	1.21	22.79	39.63	39.65
So Dau	Hong Bang	0.63	4.30	28.24	28.26
Thuong Ly	Hong Bang	1.31	31.69	69.77	69.80
Trai Chuoi	Hong Bang	0.69	30.42	54.00	54.02
Bac Son	Kien An	1.61	23.58	49.36	49.38
Dong Hoa	Kien An	3.06	14.94	27.18	27.19
Nam Son	Kien An	1.75	8.51	26.17	26.18
Ngoc Son	Kien An	0.79	0.75	11.51	11.51
Phu Lien	Kien An	0.44	0.72	10.94	10.95

Urban commune	**Urban district**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Quan Tru	Kien An	3.36	60.83	103.65	103.70
Tran Thanh Ngo	Kien An	0.71	12.99	40.23	40.25
Trang Minh	Kien An	0.49	0.15	11.77	11.78
Van Dau	Kien An	0.67	3.80	24.18	24.19
An Bien	Le Chan	0.83	54.24	84.64	84.68
An Duong	Le Chan	1.22	41.00	65.14	65.17
Cat Dai	Le Chan	1.75	45.38	69.07	69.10
Dong Hai	Le Chan	0.73	39.77	74.21	74.25
Du Hang	Le Chan	0.79	45.79	74.03	74.06
Du Hang Kenh	Le Chan	3.51	77.55	144.65	144.71
Ho Nam	Le Chan	1.05	68.24	103.31	103.36
Lam Son	Le Chan	0.88	40.93	67.56	67.59
Nghia Xa	Le Chan	1.74	42.36	66.54	66.57
Niem Nghia	Le Chan	1.90	52.48	83.00	83.04
Trai Cau	Le Chan	1.62	41.27	70.23	70.26
Tran Nguyen Han	Le Chan	1.75	60.79	93.08	93.13
Vinh Niem	Le Chan	2.84	23.51	52.24	52.26
Cau Dat	Ngo Quyen	0.30	34.55	58.78	58.81
Cau Tre	Ngo Quyen	0.14	6.53	44.24	44.26
Dang Giang	Ngo Quyen	1.56	15.08	42.95	42.97
Dong Khe	Ngo Quyen	0.68	102.18	363.62	363.77
Dong Quoc Binh	Ngo Quyen	0.35	19.92	40.32	40.34
Gia Vien	Ngo Quyen	0.14	16.47	40.13	40.15
Lac Vien	Ngo Quyen	0.41	9.30	33.79	33.80
Lach Tray	Ngo Quyen	1.17	32.04	62.57	62.59

Urban commune	**Urban district**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Le Loi	Ngo Quyen	0.44	18.67	38.43	38.45
Luong Khanh Thien	Ngo Quyen	0.72	19.55	36.54	36.56
May Chai	Ngo Quyen	0.27	1.38	23.83	23.85
May To	Ngo Quyen	0.68	19.28	49.36	49.38
Van My	Ngo Quyen	0.31	0.66	29.85	29.86
HAI PHONG URBAN TOTAL		57	1,287	2,741	2,743

The absolute mortality per urban district is summarised in Table 24. Le Chan is the most affected district due to its high density of busy roads. Hai An is the least affected, mostly because of its least populated situation.

Table 24. Number of mortality in the group +30 per district due to PM_{10}

District	Number of mortality in the group +30			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Hai An	8 (7.9-8.1)	13 (12.8-13.2)	93 (91.5-94.6)	93 (91.5-94.6)
Hong Bang	8 (7.9-8.1)	219 (215-222)	431 (424-438)	432 (425-440)
Kien An	13 (12.8-13.2)	126 (124-128)	305 (300-310)	305 (300-310)
Le Chan	21 (20.7-21.4)	633 (622-644)	1,048 (1,030-1,066)	1,048 (1,030-1,066)
Ngo Quyen	7 (6.6-7.1)	296 (291-301)	864 (850-879)	865 (851-880)
Hai Phong – urban	57 (56-58)	1,287 (1,266-1,309)	2,741 (2,696-2,788)	2,743 (2,698-2,790)

3.3.2.2. Morbidity due to PM_{10}

Morbidity is calculated for chronic obstructive pulmonary disease (COPD) and respiratory hospital admissions for PM_{10}, based on hospital records following the WHO disease classification guidelines.

$$N_{\mathrm{Extra-H}} = \frac{(H_{\mathrm{COPD}} \times 21.4\% + H_{\mathrm{Res}} \times 1\% + H_{\mathrm{Cardio}} \times 1.3\%) \times (E_{\mathrm{PM_{10}-2020}} - E_{\mathrm{PM_{10}-2007}})}{10}$$

where $N_{\mathrm{Extra-H}}$ is the number of extra hospitalisations, H_{COPD} is the number of hospitalisations due to COPD in 2007, H_{Res} is the number of hospitalisations due to respiratory diseases in 2007, H_{Cardio} is the number of hospitalizations due to cardiovascular diseases in 2007 and $E_{\mathrm{PM_{10}\text{ - }2020}}$, $E_{\mathrm{PM_{10}\text{ - }2007}}$ are the concentration of PM_{10} in 2020 and 2007, respectively (Stijn Dhondt et al. 2011).

It is estimated that more than 6,500 extra admissions to the hospital will occur in 2020 that are attributable to the increase of PM_{10} due to the increase in traffic, totalling 51,467 cases.

3.3.2.3. Morbidity due to $PM_{2.5}$

The morbidity effect of particulate matter has been calculated for $PM_{2.5}$ exposure as the number of days that normal activity will be restricted due to pollution. “Restricted-activity days” were calculated based on the concentration of $PM_{2.5}$ annual average. It is estimated that for each additional microgram of $PM_{2.5}$ in the atmosphere, there will be an additional 9.1 restricted-activity days per 100 people per year. The annual average concentration of $PM_{2.5}$ was calculated based on the annual average concentration of PM_{10} and assuming a fraction of 0.7 as $PM_{2.5}$ as suggested by the APHEIS project (S Medina et al. 2005). The results are shown that, in Hai Phong, a total of 517,180 restricted-activity days were estimated for 2007. Le Chan is the most impacted district, with a total of nearly 218,725 restricted-activity days per year, contributing to two fifths of the total restricted-activity days calculated for the Hai Phong Urban Area. The morbidity effect of particulate matter is presented in Table 25 for different growth scenarios.

Table 25. Number of restricted-activity days due to $PM_{2.5}$ in each urban district and for the four scenarios.

District	# Restricted-activity days			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Hai An	18,283	22,486	37,058	37,183
Hong Bang	77,988	95,928	158,087	158,619
Kien An	54,724	67,296	110,919	111,293
Le Chan	177,850	218,725	360,489	361,711
Ngo Quyen	91,665	112,744	185,800	186,424
Hai Phong - urban	420,511	517,180	852,352	855,230

3.3.2.4. Mortality impact of benzene

Benzene is carnogenic and is known to cause leukaemia. The estimate of cancer cases for Hai Phong according to each scenario is presented in Table 26.

Table 26. Number of annual deaths associated with benzene exposure

Health effect	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Cancer cases (95% confidence interval)	0.25 (0.18 - 0.31)	0.36 (0.27 - 0.45)	0.51 (0.37 - 0.63)	0.49 (0.36 - 0.61)

For 2007, the estimated number of cancer cases in the population associated with benzene exposure due to transportation per year is 0.36 with about 95% probability the number of cases is in the range of 0.27 to 0.45 per year.

3.3.2.5. Health impacts of noise

Health impacts of traffic noise include severe annoyance (SA), highly sleep disturbance (HSD), hypertension (HT) and ischeamic heart disease (IHD). To calculate the health impacts of noise, the "Disability Adjusted Life Year" was used. "Disability Adjusted Life Year" is the years of life that are lost due to premature mortality or disability (Anand and Hanson 1997; WHO 2014).

- ***Severe annoyance (SA) and highly sleep disturbance (HSD)***

The methods and asssumptions to calculate number of people severely annoyed by traffic noise and the corresponding DALYs were described previously in chapter 2, section 2.3.2.5.

Data used to calculate SA and HSD for the Hai Phong urban area are presented in Table 27.

Table 27. Attributes used in the calculation of SA and HSD

	L_{Aeq}	No people	Duration of response	Severity
SA	74.4	598,027	1	0.01 (0.002 – 0.12)
HSD	74.4	598,027	1	0.01 (0.002 – 0.10)

Table 27 shows the percentage of the urban population affected by SA and the absolute number of people in the Hai Phong urban area affected by Severe Annoyance (SA). 34.95% of Hai Phong urban population affected by SA and 24.88% are affected by HSD. The total DALYs is 3,577.7.

Table 28. Impact of noise: severe annoyance and highly sleep disturbance

Health outcome	Percentage of urban population severely annoyed by noise	Number of people in Hai Phong urban area affected by severe annoyance	DALYs
SA	34.95%	208,979	2,089.8
HSD	24.88%	148,794	1,487.9

- ***Hypertension (HT) and Ischaemic Heart Disease (IHD)***

Number of people affected by HT and IHD due to traffic noise is calculated based on data as shown in Table 29. The results for 2007 are presented in Table 30. The results show that although the prevalence of HID is much lower than HT but due to its very high fatality, the total DALYs for IHD is higher than HT.

Table 29. Attributes used in the calculation of HT and IHD

	L_{Aeq}	people	Duration of response	Severity	RR	Prevalence (2006)	
						cases	deaths
HT	74.4	598,027	1	0.352	1.26 (1.14-1.39)	24,232	5
IHD	74.4	598,027	1	0.35	1.09 (1.05-1.13)	913	10

Table 30. Impact of noise: hypertension and ischaemic heart disease

	AR	PAR	YLD	YLL	DALYs
HT	0.0021 (0.0012 – 0.0028)	242.16	373	85.24	458.24
IHD	0.0008 (0.0005 – 0.0012	9.11	746	3.19	749.19

Around 242 people in Hai Phong are affected by hypertension and 9 people were affected by IHD due to noise pollution. The total estimated DALYs were 1,207.43.

- ***Total morbidity effect of noise***

In total, the number of Disability Adjusted Life Years (DALYs) for Hai Phong amounted to 4,785.13 years. Severe annoyance (SA) contributes the most number of DALYs with 2,089.80 years. About 10% of the total DALYs is due to hypertension and about 15% is due to ischeamic heart disease.

Table 31. Total health effects of noise (DALYs)

Health effects	DALYs (year)
Severe Annoyance	2,089.80
Highly Sleep Disturbance	1487.9
Hypertension	458.24
Ischeamic Heart Disease	749.19
TOTAL	4,785.13

3.3.3. Uncertainty

Uncertainty in forecasting using model can be attributed to two basic sources: input uncertainty and model uncertainty (Rasouli and Timmermans 2012). Input uncertainty comes from errors in input data. The VISUM model uses data from household survey to produce the O-D matrices where errors can occur in survey design (such as creating bias between response and non-response groups) or survey data interpretation and coding. The literature suggests that a 5% population surveyed is sufficient for travel demand household survey (Ziliaskopoulos and Mitsakis 2008) but this study was undertaken based on 0,31% coverage of the total population. However, the validation of the model against observed traffic data shows that the model produces a good result in estimating traffic at any given point, with a maximum of 6% differences.

Another source of uncertainty in this study is the temporal variability in travel times, of congestion or the availability of seats has not been taken into account. This is propagated clearly in emission and dispersion models, where the models mostly produce a concentration lower than observed level of PM_{10}. Observations at major street junctions show that PM_{10} concentration is much higher than modelled, showing that the air quality model mostly underestimates concentration of PM_{10}.

Table 32. Comparison of modelled and observed concentration of PM_{10}

Junction	Modelled concentration (annual mean)	Observed concentration (annual mean)	Difference	Difference in %
A1	21,26	43,46	-22,20	-51,07%
A2	24,65	64,20	-39,54	-61,60%
A3	27,23	77,04	-49,81	-64,66%
A5	16,09	49,56	-33,47	-67,53%
A7	30,96	65,19	-34,22	-52,50%
A8	29,84	48,39	-18,55	-38,33%
A9	36,90	68,15	-31,25	-45,86%
A10	35,72	70,12	-34,40	-49,06%

Junction	Modelled concentration (annual mean)	Observed concentration (annual mean)	Difference	Difference in %
A11	19,62	53,33	-33,71	-63,21%
A12	34,45	52,35	-17,90	-34,19%
A13	24,71	48,39	-23,69	-48,95%
A14	15,24	80,99	-65,75	-81,19%
A15	24,03	26,95	-2,93	-10,86%
A16	36,45	37,53	-1,08	-2,88%
A17	19,90	44,73	-24,83	-55,52%
A19	8,13	33,58	-25,45	-75,80%

However, the difference can also be attributed to the possible contribution of other sources to the measurement, as the model estimates only the contribution of vehicular sources.

3.4. Discussion

The city of Hai Phong is growing fast as a result of urbanization and industrialization. This process is expected to continue during the next decades. The Adjusted Master Plan of Socio-Economic Development for Hai Phong until 2020 planned an overall development of 14% annual economic growth. Most of the development will happen in the industrial-construction sector, followed by the service sector. Both sectors will generate more traffic in both urban areas and the outer rings. The aims of the development policy will therefore lead to changes in transportation scenarios. This study offers data to take traffic related environmental health considerations into account in development policy. Overall, with extra deaths and an increased morbidity, the health burden is very high and can only be prevented by limiting the emissions.

“Road toll” is a concept used to describe the cost of using surface transport modes (or the roads), which is counted not in monetary term but by the number of road traffic casualties (Fisher et al. 2002; Kunzli et al. 2000). The “traffic air pollution road toll” in several European countries was much higher than the “traffic accident road toll”. This is called the accident/pollution ratio in the total road toll (Kunzli et al. 2000). This ratio for Hai Phong was 1:6.0, higher than that of France (1:3.3), Austria (1:4.1), Switzerland (1:4.8) and New Zealand (1:1.4) (Kunzli et al. 2000; Fisher et al. 2002).

This study used approaches comparable with those used in other studies in assessing environmental health impacts of traffic related PM_{10} and $PM_{2.5}$, such as the approach used in the APHEIS HIA focusing on PM in 26 European cities (S Medina et al. 2005) and the HIA for transportation in New Zealand performed by Fisher et al. (2002, 2007). The results show that the assessment of health effects remains challenging, mostly due to a number of uncertainties in different parts of the assessment process. The assessment of health risk in this study is conservative for several reasons. First, the use of PM as the indicator for air pollution has left out the health effects of other pollutants, such as NOx, SOx, and O_3, which have various independent health effects (Klea Katsouyanni 2003; Pope III 2002; Roussou and Behrakis 2005; Sunyer et al. 1997). In addition, health effects for people younger than 30 years are not considered, while this group includes children, one of the sensitive groups for lung diseases (Ballester 2005; Krzyzanowski, Kuna-Dibbert, and Schneider 2005; Moshammer, Hutter, and Schmidt 2005; Nicolopoulou-Stamati et al. 2005; Roussou and Behrakis 2005; WHO 2006a). However, health effects of benzene and noise as additional indicators show that road transport has a wide array of effects, corresponding with finding of other studies that suggested that noise have many adverse effects on human health ranging from annoyance to hearing loss and heart diseases (Jaecker-Cueppers 2011; Ruparel, Mistry, and Jariwala 2013; Chui, Heng, and Ng 2004).

Next, the study uses 52 administrative communes of the 5 urban districts of Hai Phong as the basic assessment units and assumes that the population density is homogeneous in each commune. In reality, in Hai Phong City, population density is much higher in some neighbourhoods of the city, especially along the main roads. In addition, it is clear that the distribution of particles is not homogeneous but affected by traffic intensities and therefore the proximity to major roads increase health risks

(Hoek, Brunekreef, et al. 2002). In reality, each person is exposed differently to air pollution, depending on one's activities over space and time (Ballester 2005; Chiodo and Rolfe 2000; Fisher et al. 2002; Kunzli et al. 2000; Le Tertre et al. 2002; S Medina et al. 2005). However, in this study, this variability could not be taken into account.

Also, the dispersion model did not take into account the high concentration of pollution on and along the roads. Areas further from main roads, which are partially protected by housing rows, often experience lower concentrations of air pollutants. Therefore, models generalise certain aspects of reality. However, the use of models is necessary as the alternative is to base estimations on extensive and expensive personal exposure monitoring for hard-to-define representative groups of environmentally exposed residents (Jerrett and Finkelstein 2005). Moreover, models allow annual or bi-annual assessments to monitor the environmental impacts of development as well as the application in strategic environmental assessment.

Finally, due to the lack of details in the Master Plan, future scenarios are calculated based only on the total increase in traffic, without knowing the exact distribution of traffic over the network and over time. On the one hand, this leads to possible over estimate of health burdens as new or better roads can help disperse traffic to less populated areas, hence reduce air pollution. On the other hand, better peripheral roads can provide better access to city centre, hence more traffic will be observed. Therefore, it is recommended a strategic assessment using the approach in this study must be carried out for the whole network once details on the new infrastructures become available.

To increase the accuracy of this approach, the model can be refined at different levels.

- In the current model, the zoning system for transportation planning is identical to the administrative zoning system. Therefore, patterns of estimated Origin-Destination pairs for all transport modes depend on an administrative system, which varies from the actual mobility patterns that might result if a complete transport zoning system would be (designed and) applied. A systematic O/D study could improve the model results.
- The use of a microscopic model, that would incorporate the mobility

patterns of motorcycles, will result in a better accuracy.

- Traffic flows that occur due to freight movement, primarily in the zone of the Hai Phong harbour, have not been incorporated to the model due to the lack of such information.
- Public transit should be better incorporated in the model. Currently, only bus network is included but the role of railway and its contribution to the traffic patterns are not incorporated due to the lack of data. Also, for estimating future scenarios, public transits using tram/urban trains should be incorporated as to assess the viability of using public transport to reduce traffic, emission and health burdens.
- Temporal variations of traffic patterns should be explicitly modelled, which was not considered in the current model.
- As many monitoring sites may not be truly representative of the areas being considered, in the analysis, all data was used, assuming a general degree of representativeness. Better air quality monitoring due to transportation will contribute to a greater accuracy of the approach. The maps of pollution concentration can help identify location for monitoring.
- Uncertainty and sensitivity analysis should be conducted systematically to find the most suitable models for local situation.

3.5. Conclusion

Hai Phong is a harbour and coastal city, in the eastern part of Northern Vietnam. It witnessed a very fast mobility growth during the period 2002 - 2005. The city offers a multimodal transport system, which includes airborne, waterborne, road and rail transport. This transport modi are closely linked to its economic development. The results of a health risk assessment that quantifies the mortality and the diseases associated with particulate matter pollution resulting from transport with the focus is on the integration of modelling and GIS approaches in the exposure analysis to increase the accuracy of the assessment and to produce timely and consistent assessment results so that they can support the decision-making process on urban planning and contribute to a more sustainable mobility in the Hai Phong urban area.

The use of models and GIS in a health risk assessment, from the governance point of view, can reduce the waiting time for results, in comparison to the in depth personal exposure study with better accuracy than using purely monitoring data and health statistics. The use of models and GIS allows to understand the links between air quality and health outcomes visually and is therefore useful in the decision-making process on urban planning and development of the Hai Phong urban area.

A number of improvements can be made to further advance the integration, such as a better data integration programme will facilitate the application of integrated model in policy-making. Data on mobility survey, environmental monitoring and measuring must be standardised and regularised. Various traffic models, as well as emission and dispersion models should be tested and better understanding of their uncertainty and sensitivity should be studied. Other health effects of transport can also be incorporated in the integrated model to produce more information for planners, policy makers and other stakeholders.

In summary, despite the uncertainties, the study highlights the need to consider air pollution attributed health effects in development policy. Integrated approaches should be considered when preparing development plans and a strategy to build a systematic assessment framework by further development of different modules of the models to obtain better estimation accuracy.

CHAPTER 4. HEALTH IMPACT ASSESSMENT FOR THE HA NOI CASE STUDY [6]

4.1. Introduction

Hanoi is the capital of Vietnam and the second largest city in of the country, just behind Ho Chi Minh City. During the last two decades, Hanoi developed fast and expanded steadily. Hanoi changed its boundaries 4 times in 1961, 1978, 1991 and 2008. After the last boundary modification, Hanoi covers the total area of 3,348.5 km^2; has a population of 6.45 million people with an average density of 1,926 people/km^2, distributed over 27 districts (9 urban and 18 rural) and 408 communes (as of 31 December 2008) (Hanoi Statistics Office 2009).

Hanoi experienced a 11.7‰ population growth a year in 2000, which increased to 11.8‰ in 2005, 12.5‰ in 2008 and 12.7‰ in 2009. The city is characterised by a fast urbanisation rate, achieving 5.6%/year during the period 2001-2005 but reduced to 3% during the period 2006-2009. By 2009, the urban area was 40.8%, an increase from 33.2% in 2000. Urban population accounts for around 41.3% of the total (Hanoi Statistics Office 2009; General Statistics Office 2011). In 2006, Hanoi had an unemployment rate of 6.1%, which reduced to 5.4% in 2008. The city has about 3,974 km of roads, of which 643km within the 9 old districts (that account for 6.8% of the urban area).

Since the city acquired a large part of its surroundings in 2008, Hanoi tripled its size and doubled its population. The new development aims to spread the concentrated population and economic activities to the newly acquired areas to alleviate the stress currently put on the environment due to air, noise and water pollution and the decreasing quality of life of the residents. Hanoi is a highly polluted city as a result of the dense traffic and the industry that is still localised in the inner city.

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[6] This chapter is based on Hieu, V. V., Quynh, L. X., Ho, P. N. & Hens, L., 2013. Health Risk Assessment of Mobility-Related Air Pollution in Ha Noi, Vietnam. Journal of Environmental Protection (2013), 4:1165-1172.

Hanoi has a very fast growing fleet of motor vehicles, at the rate of 12%-15% annually. Both cars and motorcycles grow rapidly. In 2000, around 46,200 cars/trucks circulated in the city, accounted for 9.5% of the country's total vehicle fleet. Its 865,232 motorcycles comprise 12.38% of the country's motorcycle fleet (Vietnam Register 2002). By the end of 2009, there are more than 2.76 million motorcycles in circulation. The number of cars doubled during the period 2005-2009, raising from nearly 150,000 cars in 2005 to more than 304,000 in 2009 (Vietnam Register 2010). The fast transition from bikes to motorcycles (since the middle of the 1990s) and to cars (since the late 1990s) results in a most serious environmental burden in particular on the air quality and the associated human health impacts.

Motorised mobility is a major source of air pollution. Studies in large cities in developing countries such as New Dehli (India), Bangkok (Thailand), Beijing (China), Manila (the Philippines) and Jakarta (Indonesia) show a 40%-80% contribution of vehicles to the total concentration of particulate matters (Bruce, Perez-padilla, and Albalak 2000; Bruce, Perez-Padilla, and Albalak 2002; Syahril, Resosudarmo, and Tomo 2002; Walsh 2002; Kan and Chen 2004; Cheng et al. 2007; Sagar et al. 2007). Particulate matter (especially PM_{10}) and their effects on human health have been the subject of many epidemiological studies and reviews. The results consistently show that 24-hr average concentrations of particulate matters are related to daily mortality and daily hospital admissions (Dockery et al. 1993; C A Pope, Dockery, and Schwartz 1995; Pope III 2002; Anderson et al. 2004; Fisher et al. 2007). Chronic exposure to PM_{10} is also linked to mortality (Ballester 2005; Kunzli et al. 2000; Le Tertre et al. 2002; S Medina et al. 2005; Fisher et al. 2002; Fisher et al. 2007).

In Vietnam, studies on health impacts of air pollution have been done recently in selected major cities, such as Ho Chi Minh City, Ha Noi and Hai Phong. Nguyen (2001) studied the impacts of air pollution on human health in Hanoi using published dose-response functions to calculate long-term health impacts of Total Suspended Particles (TSPs) using air quality data for the period 1994-1998. Most of the other recent studies use health surveys as the main method to assess the health effects on the population. These health surveys are based on the presence/absence of chronic obstructive pulmonary diseases (COPD) and respiratory diseases.

This chapter overviews the air quality and pollution caused by road traffic in central Hanoi (5 old districts) and the related health outcomes due to particulate matters. It uses dose-response functions to quantify the number of extra deaths resulting from traffic-related air pollution. The results are compared with those of other studies to assess the impacts of air pollution on human health in large, crowded and fast developing cities like Hanoi.

4.2. Materials and methods

4.2.1. Air monitoring

Air quality monitoring data were obtained from the Environmental Monitoring Centre of the National Environmental Agency. They include information of air pollutants (CO, SO_2, NO_2 and TSP) and noise, measured quarterly during the period 2005-2009 at 5 monitoring locations. Figure 14 shows the geographical distribution of the monitoring stations. They are located in a way that the data provide a fair idea of the average pollutant concentrations 5 districts downtown Hanoi, which are Ba Dinh, Dong Da, Hai Ba Trung, Hoan Kiem and Thanh Xuan.

Figure 14. Map of monitoring locations

4.2.2. Health risk assessment

Health risk assessment using the classic 4-step paradigm:

- **Hazard Identification** has been done based on literature review and ground-checked through a health survey. Health impacts of various air pollutants, especially PM, benzene, and ground level ozone have been extensively described (Anderson et al. 2004; Ballester 2005; Bruce, Perez-padilla, and Albalak 2000; Bruce, Perez-Padilla, and Albalak 2002; Fisher et al. 2002; Janssen and E 2004; Kunzli et al. 2000; Le Tertre et al. 2002; S Medina et al. 2005; Nicolopoulou-Stamati et al. 2005; Roussou and Behrakis 2005; WHO 2000; Krzyzanowski, Kuna-Dibbert, and Schneider 2005; WHO 2006a; Klea Katsouyanni 2003). Most of the epidemiological evidence points to the link between exposure to air pollutants and respiratory and cardio-vascular diseases, such acute upper respiratory infections (acute pharyngitis, acute tonsillitis, acute laryngitis and tracheitis, etc.), influenza and pneumonia, acute bronchitis and bronchiolitis, and primary hypertension. In this study, the mortality effect of PM_{10} and the morbidity effects of $PM_{2.5}$ will be considered.
- **Exposure assessment**: due to insufficient data (such as detailed population density data, air quality values for small unit, and population activities indoor-outdoor, etc.), it is supposed that the whole of the population in the 5 assessed districts of Hanoi exposed to the same level of outdoor air pollution. The annual concentration of the monitoring station for the period 2005-2009 was used.
- **Dose-Response assessment** follows the dose-response function for PM_{10} established by prior research that has been published (Kunzli et al. 2000; S Medina et al. 2005; Fisher et al. 2002; Fisher et al. 2007). These data shown an increase in mortality of 4.3% per 10 $\mu g/m^3$ increase in PM_{10} (Table 33).

Table 33. Dose-response relationship used in Kunzli et al. 2000

Health outcome	Relative risk (RR) [a]	95% CL [b]
Total mortality (adults >30 years, excluding violent deaths)	1.043	1.026 - 1.061
[a] Relative risk associated with a 10 $\mu g/m^3$ increase in PM_{10} [b] 95% confidence level		

- **Risk characterisation** was assessed based on the number of extra cases of health outcome linked to traffic-attributable air pollution. **For $PM_{2.5}$**, the number of restricted-activity days were calculated as proposed by Fisher et al. (2002) at 9.1 cases per 100 persons per 1 µg/m^3 annual $PM_{2.5}$. The formula for calculation is

$$\mathbf{N_{RAD} = E_{PM2..5} * (9.1 * P_{exp} / 100)}$$

Where N_{RAD} is the number of restricted-activity days; $E_{PM2.5}$ is the annual concentration of $PM_{2.5}$ and P_{exp} is the exposed population. The number of restricted-activity days experienced by an individual in the course of a year is an important measure of functional well-being. The definition of "restricted-activity days" is the average annual number of days a person experienced at least one of the following: (1) a bed day, during which a person stayed in bed more than half a day because of illness or injury related to traffic; (2) a work-loss day, on which a currently employed person missed more than half a day from a job or business; (3) a school loss day, on which a student 5-17 years of age missed more than half a day from the school in which he or she was currently enrolled; or (4) a cut-down day, on which a person cuts down for more than half a day on things he usually does.

For PM_{10}, the number of extra deaths was calculated using the formula (Kunzli et al. 2000) that allows to calculate the long-term impact of PM_{10} on mortality within the group aged over 30 years old:

$$\mathbf{Po = Pe/(1+((RR-1)(EPM - BPM)/10))}$$

where:

- Po = baseline mortality per 1,000 in the age group 30+, after deducting the air pollution effect (this will depend on the other variables)
- Pe = crude mortality rate per 1,000 in the age group 30+. Due to the lack of specific data, the crude mortality rate for whole population of each assessed district will be used. Data comes from GSO (2009).
- E_{PM} = PM_{10} exposure level in the area of interest (µg/m^3).

- B_{PM} = threshold PM_{10} exposure level for mortality effect. In this study, with an assumed threshold for PM_{10} at 7.5 (Fisher et al. 2002).
- RR = epidemiologically derived relative risk for a 10 μg/m^3 increment of PM_{10}, assuming a linear dose-response relationship above the threshold (B) for the age group 30+.

The increased mortality is calculated using the following formula:

$$\mathbf{D_{PM} = Po * (RR - 1)}$$

where: D_{PM} = number of additional deaths per 1,000 people in the age group 30+ for a 10 μg/m^3

The number of deaths due to PM_{10} is calculated as follows:

$$\mathbf{N_{PM} = D_{PM} * P_{30+} * (E_{PM} - B_{PM})/10}$$

where: P_{30+} is the population over 30-years old (47.1% of the total population of Hanoi according to the 2009 Nationwide Population Survey and Population Projection until 2050)

4.3. Results

4.3.1. Air quality

According to the Vietnamese National Environmental Agency, in Hanoi, the fleet of motor vehicles increases at the rate of 12%-15% per year. Both the number of cars and of motorcycles increases rapidly. By the end of 2009, it is estimated that there are more than 2.76 million motorcycles in circulation.

The vehicle inventory for Hanoi shows that, by the end of April 2010, Hanoi traffic is dominated by motorcycles with more than 3.6 million units in operation. There are nearly 160 thousand cars and nearly 68 thousand trucks. 94% of the vehicle pool in Hanoi are motorcycles (Phạm et al. 2010).

Motorcycles produce the most VOC for each kilometer travelled. They emit ten times more VOCs than a car and 1.5 times more than a bus (Krzyzanowski, Kuna-Dibbert, and Schneider 2005). The motorcycle fleet also emits more CO. As its capacity is lower than this of a car and much lower than this of a bus, consequently, the pollution level per passenger kilometre is the highest of all motorised traffic. Therefore, as the preferred mode of transport, accounts for 94% of the fleet, and around 85% of the total road length travelled (Table 34), motorcycles are the main source of air pollutant emissions in Hanoi city.

Cars become gradually more popular in Hanoi. Their number has nearly doubled between 2005 and 2009 (from 149,333 units in 2005 to 304,143 units in 2009) (Vietnam Register 2010).

Based on the number of vehicles in circulation, pollution emissions can be assessed. Table 34 below shows the estimation of air pollution emissions from motorised traffic sources in Hanoi.

Table 34. Emission by vehicle types in Hanoi (Phạm et al. 2010)

Vehicle type	**Travelled distance (km)**	**Emissions (tonne/year) for 2009**				
		TSP	SO_2	NO_x	CO	VOC
Motorcycle	5,858	1,710.21	6.09	2,992.88	357,007.38	171,021.50
Car	6,205	69.30	1.01	1,178.18	7,643.34	821.76
Passenger car and bus	14,600	328.78	0.77	3,874.88	1,549.95	1,244.66
Truck	5,475	290.03	0.80	3,272.10	7,838.16	1,446.42
TOTAL		**2,398.32**	**8.68**	**11,318.03**	**374,038.83**	**174,534.33**

The table above shows that motorcycles contribute the most to the total traffic emissions. They account for over 70% of the total TSP emissions and more than 95% of the total VOC emissions.

Hanoi has 5 air quality monitoring stations that were in operation during the period 2007-2009. Average annual air quality data at the stations is presented in Table 35.

Table 35. Annual concentration of dust (TSP) in Hanoi at five monitoring stations

Year	**Average annual TSP concentrations (mg/m^3)**				
	Thuong Dinh (Thanh Xuan district)	Mai Dong (Hai Ba Trung district)	Ly Quoc Su (Hoan Kiem District)	Van Phuc (Ba Dinh district)	Kim Lien (Dong Da district)
2007	0.28	0.4	0.26	0.19	0.68
2008	0.36	0.29	0.25	0.23	0.48
2009	0.40	0.415	0.26	0.20	0.46

Monitoring results show that the daily concentrations of PM_{10} fluctuate with a large difference between day-time and night-time concentrations. During peak hours (around 8am and 6pm), the concentrations of PM_{10}, CO and NO_2 are highest, showing the impacts of the traffic on air quality. While during night-time (9pm to 5am next day), PM_{10} concentration is mostly below the standards (QCVN 05:2009), concentrations during the day are 2 to 3 times higher than the standard (Ministry of Transport of Vietnam 2010).

The annual average concentrations of PM_{10} are higher than the standards for 3 consecutive years in 2007, 2008 and 2009. For NO_2 and SO_2, hourly concentrations are within the permissible levels but daily concentrations are higher than the standards.

4.3.2. Health effects

In this study, the mortality attributed to PM_{10} and the morbidity of $PM_{2.5}$ are assessed. As for the mortality, the results provide a figure on additional (or extra) deaths caused by the increased of the concentrations of PM_{10}. The increased mortality due to PM_{10} exposure for the group over 30-years is presented in Table 36. Only the urban sections of Hanoi are taken into account in the calculation for area and population.

The concentrations of PM_{10} are calculated based on the monitored concentration of TSP (Table 35). As all monitoring points are located next to streets and are designated as traffic air pollution monitoring stations, the concentrations of TSP are considered 100% traffic-attributable. The average annual concentration of

PM_{10} is estimated at 55% of the average annual concentration of TSP (which is the average across all monitoring points) (Dixon et al. 2013).

Table 36. Absolute mortality due to PM_{10} in the period 2007-2009

District	Year	Area	Population	Density	Pop 30+	E_{PM}	Po	D_{PM}	N_{PM}
Ba Dinh	2007	9.25	222,200	24,022	104,656	104.50	0.14	0.46	463
	2008	9.25	223,800	24,195	105,410	126.50	0.12	0.40	507
	2009	9.25	225,000	24,324	105,975	110.00	0.15	0.48	526
Dong Da	2007	9.96	361,100	36,255	170,078	374.00	0.04	0.13	798
	2008	9.96	365,500	36,697	172,151	264.00	0.06	0.19	854
	2009	9.96	371,000	37,249	174,741	253.00	0.06	0.19	832
Hai Ba Trung	2007	10.09	311,200	30,842	146,575	220.00	0.07	0.22	694
	2008	10.09	310,000	30,723	146,010	159.50	0.11	0.35	772
	2009	10.09	297,600	29,495	140,170	228.25	0.08	0.25	776
Hoan Kiem	2007	5.29	150,300	28,412	70,791	143.00	0.15	0.50	484
	2008	5.29	148,600	28,091	69,991	137.50	0.17	0.57	518
	2009	5.29	147,000	27,788	69,237	143.00	0.17	0.56	529
Thanh Xuan	2007	9.08	216,400	23,833	101,924	154.00	0.07	0.23	346
	2008	9.08	221,700	24,416	104,421	198.00	0.05	0.18	356
	2009	9.08	224,900	24,769	105,928	220.00	0.06	0.21	466

The results (N_{PM}) indicate the absolute increase in mortality and not the adjusted values reflecting the year-life-lost. At the annual threshold of 7.5 µg/m^3, the estimated number of people dying by non-external causes that may be associated with traffic air pollution is 2,785 in 2007, 3,007 in 2008 and 3,129 in 2009. Table 36 above shows that the mortality due to PM_{10} has been increased slightly during the period 2007-2009. Amongst the 5 assessed districts, Dong Da has the highest tolls even though it has the lowest number of additional deaths per 1,000 people in the age group 30+ for each increment of 10 µg/m^3 (D_{PM}). This is because it has the worst air quality index. Thanh Xuan has the lowest tolls although it is not the district with the best air quality, thanks mostly to its low crude death rate, which could be the result of younger population overall.

For morbidity, the total number of restricted-activity days due to $PM_{2.5}$ exposure was calculated and presented in Table 37. The calculation assumed that $PM_{2.5}$ effect on morbidity has no threshold (or threshold is 0). As there is no measurement for $PM_{2.5}$ concentration, the fraction of 0.7 was applied on the concentration of PM_{10} to calculate the concentration of $PM_{2.5}$, as suggested by S Medina et al. (2005).

Table 37. Evolution of the number of restricted-activity days during $PM_{2.5}$ over the period 2008-2009

District	Year	Population	E_{PM}	$E_{PM2.5}$	N_{RAD}	Average per head
Ba Dinh	2007	222,200	104.50	73.15	1,479,108	6.7
	2008	223,800	126.50	88.55	1,803,392	8.1
	2009	225,000	110.00	77.00	1,576,575	7.0
Dong Da	2007	361,100	374.00	261.80	8,602,774	23.8
	2008	365,500	264.00	184.80	6,146,540	16.8
	2009	371,000	253.00	177.10	5,979,073	16.1
Hai Ba Trung	2007	311,200	220.00	154.00	4,361,157	14.0
	2008	310,000	159.50	111.65	3,149,647	10.2
	2009	297,600	228.25	159.78	4,326,963	14.5
Hoan Kiem	2007	150,300	143.00	100.10	1,369,098	9.1
	2008	148,600	137.50	96.25	1,301,550	8.8
	2009	147,000	143.00	100.10	1,339,038	9.1
Thanh Xuan	2007	216,400	154.00	107.80	2,122,841	9.8
	2008	221,700	198.00	138.60	2,796,213	12.6
	2009	224,900	220.00	154.00	3,151,749	14.0

Table above shows that annually, each person in Hanoi City loses around 14 days in 2007, 12 days in 2008 and 13 days in 2009 due to $PM_{2.5}$ pollution. People in Dong Da District lost the most days due to air pollution and people in Ba Dinh District lost the least.

4.4. Discussion

In Hanoi, the economic development and fast urbanisation are associated with a very fast increase in the vehicle fleet, with an annual growth of about 11% in the number of cars and 15% in the number of motorcycles. The average trip per person per day for Hanoi in 2005 was 2.7 with a average daily travelled distance of 20-25 km, which is much higher than other countries in the region (Phạm et al. 2010).

Traffic contributes largely to the air pollution in the city and accounts for about 70% of the total pollution. TSP/PM_{10} in all measurements and monitoring points is higher than the Vietnamese standards and much higher than the level that has impacts on health. Concentrations of other pollutants such as SO_2, NO_x, and CO are in general lower than the annual standard but sometimes exceeds daily standards. Moreover, variations are noticed during the day. Concentrations of pollutants during the morning and afternoon peak hours are always 1.5 to 5 times above the hourly standards. This corresponds with the peak number of vehicles in circulation and frequent congestions on many streets in Hanoi.

Calculation of the health risk caused by traffic shows that mobility in Hanoi causes a high health burden. In 2009, mobility caused 3200 extra deaths by traffic related PM_{10}.

Table 38 shows that health impacts due to air pollution is by far larger than the number of fatalities due to traffic accidents. The combination of mortality due to traffic accidents and due to air pollution is called “traffic road toll”. In Hanoi, this “road-tolls” is much higher than other countries (Fisher et al. 2002; Kunzli et al. 2000; Hieu et al. 2010).

Table 38. Total mortality due to traffic accident and air pollution

Country	**Population (million)**	**Mortality due to traffic accidents for all ages (1)**	**Mortality due to traffic air pollution for adults > 30 (2)**	**Ratio (1)/ (2)**
France (1996)*	58.3	153 per million	501 per million	1 : 3.3
Austria (1996)*	8.1	119 per million	487 per million	1 : 4.1
Switzerland (1996)*	7.1	84 per million	400 per million	1 : 4.8
New Zealand (2002)+	3.7	137 per million	196 per million	1 : 1.4
Hai Phong, Vietnam (2007)#	0.6	307 per million	1572 per million	1: 5.1
Ha Noi, Vietnam (2009)	2.6	174 per million	2473 per million	1: 14.2

* Kunzli et al. (2000) + Fisher et al. (2002) # Hieu et al. (2010)

However, there are several uncertainties in this study. First of all, time-series data on health impacts of air pollution is not available in Vietnam. The use of dose-response functions from other studies worldwide may show discrepancies while applying them to the situation in Hanoi. As dose-response relationships can vary from population to population, specific dose-response relationships for Vietnam are necessitated in future studies.

Also, there is no division between mortality due to fine and ultrafine particulates as the current study on the impact of $PM_{2.5}$ on mortality was not available to be applied in Hanoi. Increasing evidence points to the direction that $PM_{2.5}$ is actually the culprit behind mortality due to particulate matter. Therefore, the higher the proportion of $PM_{2.5}$, the higher mortality will be. From this point of view, current estimate on mortality is conservative.

In addition, exposure to different air pollutants is simplified in this study, due to the lack of monitoring data as well as a reliable air quality modelling methods that allow to accurately calculate the number of people exposed to different levels of pollution by individual air pollutants. This necessitates further studies on air quality and air pollution exposure for Hanoi.

It is worthy to note that the results are indicative, as PM was chosen as the representative pollutant. Other pollutants also contribute to different health effects, such as increase in hospitalisation due to air pollutants (NOx, SO_2, VOC) or mental health issues due to noise and traffic disturbances. Those health effects cannot be included in the scope of this chapter.

CHAPTER 5. DISCUSSIONS AND CONCLUSIONS

5.1. HIA for traffic in Hai Phong and Hanoi

The case-study of HIA of traffic-related emissions in Hai Phong and Hanoi used a quantitative approach integrating health with environmental assessment. The HIA procedure includes hazard identification, exposure analysis, dose-effect relationships and risk assessment. Exposure assessment used a model which calculates the concentrations of PM_{10} based on traffic volumes an emission factors. PM_{10} was chosen as the indicator pollutant and health outcomes associated with this pollutant are quantified using epidemiological dose-response relationships. Modelling and GIS approaches allow estimating exposure. This starts with using the VISUM transport model to forecast mobility flows in different parts of the city. The results of the transport model are integrated in an emission model, which allows calculating emissions along roads. GIS was used in a dispersion model to calculate concentrations of air pollutants on a continuous range and to display them on a concentration map. When overlaying the concentration map with the population density map, human exposure to pollution can be estimated. Finally, health effects are calculated based on dose-response functions using the quantified exposures and relative risks figures from the literature (Hieu et al. 2013b; Hieu et al. 2010; Stijn Dhondt et al. 2011).

This research used approaches which are comparable with those used in other studies in assessing environmental health impacts of traffic related PM_{10} and $PM_{2.5}$. Examples include: the APHEIS HIA focusing on PM in 26 European cities (S Medina et al. 2005; S Medina et al. 2009) and the HIA for transportation in New Zealand (Fisher et al. 2007; Fisher et al. 2002).

To assess exposure in the Hai Phong case, the concentrations of PM_{10} were modelled for 4 transport scenarios, each for 2 worst-cases: maximum values during 24 hours and maximum value for 1 year, based on the results of the transport model calculating the number of vehicles on the Hai Phong roads for each of the 4 modes of transport (bicycle, car, motorcycle and truck) and for each of the 4 scenarios, as described in chapter 3. The concentration maps were then overlaid with the city maps using a GIS to produce maps of PM_{10} concentrations by intervals. Concentration maps for the max-24hours- mean are with the interval of 10 $\mu g/m^3$ and concentration maps for the max-annual-mean with the interval of 3 $\mu g/m^3$. The results show that the max-24hours-mean level of PM_{10} pollution is very high. The highest concentrations are found in the center of the city ranging between 50 to 60 $\mu g/m^3$. The maximum annual mean of 20-23 $\mu g/m^3$ is less polluting. Most of the population in Hai Phong is exposed to the PM_{10} concentration ranging between 15$\mu g/m^3$ – 30 $\mu g/m^3$ (Hieu et al. 2013b).

The current shift from bicycles and motorbikes to private cars hardly influences the PM concentration between scenarios 3 (30% overall growth of all modes) and 4 (30% growth and 10% modes shift to cars) by 2020. When there is a shift from motorbikes to private cars, the changes will occur with more emissions at higher range of concentrations between 20-25$\mu g/m^3$. As a result, more people will be exposed to concentrations of PM_{10} between 15-20$\mu g/m^3$ in scenario 3, while more people will be exposed to the concentrations of PM_{10} between 20-25$\mu g/m^3$ in scenario 4. Based on the exposure maps, mean concentrations of PM_{10} were calculated for each of the 52 communes in Hai Phong City. The Le Chan District has the highest number of communes with high concentration of PM_{10} (Hieu et al. 2013b).

The estimated number of people downtown Hai Phong who died in 2007 as a result of traffic related PM_{10} totals 1,288 persons. Le Chan is the most affected district due to its high density of busy roads. Hai An is the least affected, merely as a result of the limited population density. Chronic Obstructive Pulmonary Disease (COPD) caused by air pollution will often result in an increase in the admissions to the hospitals. It is estimated that, by 2020, traffic in Hai Phong will increase by 30% as compared to 2007. The forecasted concentration of PM_{10} (at unchanged policy) for 2020 is 24.44 $\mu g/m^3$. This coincides with an increase of 6.77 $\mu g/m^3$ as compared to the level of 2007. The number of extra hospital admissions was calculated using the admissions in 2006 as the baseline scenario. It is estimated that more than 6,500 extra COPD admissions to the hospital are expected for 2020 as a result of the increase of PM_{10} due to the increased traffic (Hieu et al. 2013b)

The morbidity caused by particulate matter has been calculated for $PM_{2.5}$ exposure as the number of days that normal activity will be restricted due to pollution. "Restricted-activity days" were calculated based on the concentration of the $PM_{2.5}$

annual average. The results show that, in Hai Phong, a total of 517,180 restricted-activity days were estimated for 2007. Le Chan is the most impacted district, with a total of nearly 218,725 restricted-activity days per year, contributing to two fifths of the total restricted-activity days calculated for the Hai Phong Urban Area (Hieu et al. 2013b).

For the Hanoi HIA case study, air quality data for the period 2007-2009 was used for the HIA. Similar to the results in Hai Phong, the study in Hanoi shows that the mortality attributed to PM_{10} for the group over 30-years is 2,785 in 2007, 3,007 in 2008 and 3,129 in 2009. Amongst the 5 assessed districts, Dong Da has the highest tolls even though it has the lowest number of additional deaths per 1,000 people in the age group 30+ for each increment of 10 $\mu g/m^3$ (D_{PM}) as it has the worst air quality index. Thanh Xuan has the lowest toll although it is not the district with the best air quality, thanks mostly to its low crude death rate, which could be the result of younger population overall (Hieu et al. 2013a).

For morbidity, the total number of restricted-activity days due to $PM_{2.5}$ exposure was calculated and presented. The calculation assumed that $PM_{2.5}$ effect on morbidity has no threshold (or a threshold of 0). Data shows that annually, each person in Hanoi City loses around 14 days in 2007, 12 days in 2008 and 13 days in 2009 due to $PM_{2.5}$ pollution. People in the Dong Da District lose the most days due to air pollution and people in Ba Dinh District lose the least (Hieu et al. 2013a).

5.2. Strengths of the approach

The use of combined modelling and GIS for exposure assessment has several strengths. The approach is interdisciplinary and allows to cover various aspects in one study. Various disciplines are involved, such as mathematical modelling, geographical mapping, health, environment, and sociology. GIS allows integrating knowledge from other disciplines and quantification of effects on health. GIS helps to bridge between various steps during HIA and also presents visualised results for the reporting/decision-making step.

The use of models/GIS can also speed up the process as the models can be run fairly quickly. Although the initial set-up of the model and the data requirements are heavy, the results can be quickly achieved. Once the model is established, calculation can be completed within days. GIS allows to integrate data from disparate sources to produce new information. This is the added value of interdisciplinary studies where various disciplines are involved in the process of data generation and analysis (Boulos 2004). The use of models/GIS also allows replication to other cases fairly easy as the procedure can be documented and follows standard modelling and GIS practices. It can be replicated in other locations with similar features without new models or substantial modifications are needed.

The models/GIS combination also allows covering large spatial and temporal frames. Spatial and temporal changes can be integrated into the GIS and can be visualised to promote creative problem identification, solving and decision-making (Boulos 2004). This is a main advantage, especially in the analysis of future plans, including HIA for policy options.

Using particulate matter as health effect indicators of air pollution also offers advantages. Particulate matter has been used as an indicator of air pollution in wide range of assessments. Researches both confirm and reject the representativeness of PM as indicative pollutant in health research. "Particulate matter" is a complex mixture of small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. The size of the particles is directly linked to their health impact. Of particular concerns are particles that are smaller than 10 micrometers in diameter because these can pass through the throat and the nose and affect the lungs. Once inhaled, these particles can affect the lungs, taken up by the blood and transported to the heart, which are the target organs of PM. Particles can be classified into two main groups: "inhalable coarse particles" and "fine particles". "Inhalable coarse particles", such as those found near roadways and dusty industries, measure between 2.5 and 10 micrometers in diameter. "Fine particles", such as those found in smoke and haze, are smaller than 2.5 micrometers in diameter. These particles can be directly emitted from sources such as forest fires, or they are formed when gases that are emitted from power plants, industries and automobiles react in the air.

Numerous studies linked particle pollution exposure to a variety of problems, including increased respiratory symptoms, such as irritation of the airways, coughing, or difficult breathing, decreased lung function, aggravated asthma, development of chronic bronchitis, irregular heartbeat, non-fatal heart attacks, and premature death in people with heart or lung disease. People with heart or lung diseases, children and older adults are the most likely to be affected by particle pollution exposure. However, even for healthy people, temporary symptoms might result from exposure to elevated levels of particle pollution.

5.3. Research gaps and improvement opportunities

The results show that the assessment of health effects remains challenging, mostly due to a number of uncertainties in different parts of the assessment process. The assessment of health risks in this study can be improved considering the following aspects.

5.3.1. Choosing an indicator pollutant for HIA

Short-term exposure to particulate matters can have effects such as lung inflammation, respiratory symptoms, adverse effects on the cardiovascular system, increase in medication usage and hospital admissions, and increased mortality. Long-term exposure can increase lower respiratory symptoms, reduce lung function, increase chronic obstructive pulmonary disease, reduce life expectancy, owing mainly to cardiopulmonary mortality and probably to lung cancer (Atkinson et al. 2001; Pope III 2002; Sunyer et al. 1997; WHO 2006b). Children, elderly, people with prior health problem are sensitive groups who generally suffer more from these effects (Roussou and Behrakis 2005; Krzyzanowski, Kuna-Dibbert, and Schneider 2005; Moshammer, Hutter, and Schmidt 2005; Nicolopoulou-Stamati et al. 2005) .

The use of PM_{10} as a flagship indicator can further be supported as recent new evidence points to the greater impacts of $PM_{2.5}$ both for short and long-term exposures. Health effects caused by long-term exposure to $PM_{2.5}$ include premature death, especially related to heart disease, and cardiovascular effects. Long-term exposure to $PM_{2.5}$ is also linked to reduced lung development, the development of chronic respiratory diseases (asthma in children), increased risk of contracting cancer, and harmful developmental and reproductive effects (infant mortality and low birth weight). Health effects caused by short-term exposure to $PM_{2.5}$ include premature deaths, especially death related to heart and lung diseases, increased hospital admissions and emergency department visits for cardiovascular effects (such as non-fatal heart attacks and strokes) and respiratory effects (asthma attacks, increased respiratory symptoms such as coughing, wheezing and shortness of breath). In addition, short-term $PM_{2.5}$ exposures are also linked to reduced lung function, especially in children and people with lung diseases, such as asthma.

The use of PM as the indicator for air pollution has left out the health effects of other pollutants. Many studies point to separate health burdens of pollutants such as NOx, SOx, O_3 and benzene as well as other issues (such as noise and accidents) linked to transport. Oxides of nitrogen (NO_x) (primarily nitric oxide (NO) and nitrogen dioxide (NO_2)) are gases formed by the oxidation of nitrogen and has a major role in the formation of photochemical oxidants (such as ozone) and particles (such as nitrates). NO_2 is an air pollutant that contributes both to morbidity and mortality, affects directly the lung tissue, provokes an inflammatory reaction on the surfaces of the lung especially in susceptible groups such as young children, asthmatics, and those with chronic bronchitis and related conditions (Streeton 1997). Increased lung cancer incidence has also been reported in a large case-control study, but NO_2 was primarily studied as an indicator of air pollution exposure from vehicle emissions, and so other air pollutants from vehicles may have been the cause of the cancers (Pope III 2002; Nyberg et al. 2000; P Nafstad et al. 2003; Trédaniel et al. 2009; Raaschou-Nielsen et al. 2011). Ground-level ozone is a secondary air pollutant, which has respiratory tract impacts (Bell, Dominici, and Samet 2005; Medina-Ramón, Zanobetti, and Schwartz 2006; Ito, De Leon, and Lippmann 2005). Numerous studies have linked ground-level ozone exposure with a variety of problems, including chest pain, lung irritation that can cause inflammation, wheezing, coughing, and breathing difficulties, aggravated asthma, reduced lung capacity, and increased susceptibility to respiratory illnesses like pneumonia and bronchitis (Bell, Dominici, and Samet 2005; Medina-Ramón, Zanobetti, and Schwartz 2006; S Dhondt and Hens 2009). There is no indication of a threshold concentration for health effects but rather a continuum in which higher concentrations, longer exposure, and greater activity levels during exposure cause greater adverse effects (Streeton 1997; WHO 2006a; Krzyzanowski and Cohen 2008). Sulphur oxides (primarily SO_2 and lesser quantities of sulphur trioxide (SO_3) are potent respiratory irritants, and are associated with increased hospital admissions for respiratory and cardiovascular disease (Kjellstrom, Neller, and Simpson 2003), as well as mortality (K Katsouyanni et al. 1997). Asthmatics are particularly susceptible. Volatile organic compounds (VOCs), which include benzene, have major carcinogenic effects. Moreover they damage to the central nervous system and irritate the skin (Fisher et al. 2002).

Motor vehicles are the major sources of those air pollutants in urban areas. They cause significant health effects and are included in air quality guidelines of WHO (WHO 2006a). Most countries established standards for these substances. However, they often exist in combination with each other and cause similar effects. Therefore, it is most likely that the sum of the effects of individual pollutants will be overlap. Also, most of those pollutants are included in studies of particulate matter. Data which are needed for calculating health effects of air pollutants require extensive hospital records, which often lack in detail or continuity in developing countries, such as the case of Hai Phong. Therefore, these health impacts are not included in this research.

Urban transport also causes noise, which can have several health effects such as annoyance, impaired communication and increased aggression. Other adverse effects include reduced school performance, disturbed sleep and fluctuating temper , as well as cardiovascular effects and hearing impairment (Passchier-Vermeer and Passchier 2005). The degree of annoyance increases on par with the level of the noise. WHO (2000) points out that people are moderately annoyed at 50dB L_{Aeq}, while at 55dB L_A's serious annoyance occurs. During night-time, the threshold for being annoyed is lower, and also sleep disturbance occurs. Three groups of sleep disturbance are described: primary effects, secondary effects and long-term effects. Primary effects include the effects like difficulties in falling asleep, awakenings, sleep stage changes and instantaneous arousal effects during sleep (temporary increase in blood pressure, heart rate, vasoconstriction, release of stress hormones in the blood, increased motility) (Nicolopoulou-Stamati, Hens, and Howard 2005). Secondary or *after effects* occur the next day and include the decrease of perceived sleep quality, increased fatigue and decrease in mood and performance. Long-term effects on well-being include increased medication use or chronic annoyance (Nicolopoulou-Stamati et al. 2005). In addition, annoyance caused by noise also cause impaired communication and increases aggression. When background noise surpasses the 55dB L_{Aeq}, people have to raise their voice while their concentration is interfered (WHO 2000). This complicates communication and causes annoyance. Loud noise also increases aggressive behaviour in predisposed individuals, while at noise levels above 80dB L_{Aeq} one's willingness to help other people reduces (WHO 2000). When exposed to high noise levels (above 70dB L_{Aeq}) for a long time, hearing impairment can happen. Noise can cause sleep disturbances especially when sound levels above 30dB L_{Aeq} (steady-state continuous noise) or 45dB L_{Amax} (noise events) are reached (WHO 2000). Ischaemic heart disease and hypertension are also effects associated with noise exposure. Sound levels above 65 to 70dB L_{Aeq} during the daytime can be risky, although these effects are rather small. It is evident that the choice of health effect indicators cannot be confined to only PM_{10}. Health effects of noise, both physically through illness and mentally, should also be considered.

5.3.2. The use of modelling and GIS

While the methodology for HIA in this study follows generally accepted principles, major differences have been found in the exposure assessments. In the case of Hai Phong, air pollution has been measured in only 1 monitoring site. Other monitoring sites are designed to record air pollution because of nearby industrial plants or zones. Consequently, dispersion modeling is needed for the exposure assessment. During the course of the research, several air quality measurement campaigns were carried out to validate the model. The measured data of the validation showed a fairly good agreement with the modelled levels, although the model in general underestimated the particle concentrations. This may be caused by the lack of information on a background concentrations and an incomplete emission database; for example the high levels of PM measured at springtime because of road dust.

The model used to estimate the transport requires a variety of data that must be collected systematically, such as demography, household travel preferences and practices, vehicular fleet registry, traffic observations, road network configurations, etc. When these data are completing the Origin-Destination matrix, an Origin-Destination map can be produced. On the other hand, demographic data is often collected and stored based on administrative geographical zones. This difference in data collection and requirements dovetails in the different methods disciplines use in researching their subjects. Conciliation is therefore essential. This study covers 52 administrative communes of the 5 urban districts of Hai Phong as the basic assessment units. Therefore, patterns of estimated Origin-Destination pairs for all transport modes depend on an administrative system, which varies from the actual mobility patterns that might result if a complete transport zoning system would be (designed and) applied. To improve the model results, a systematic Origin-Destination study should be conducted. In addition, administrative zone can be defined covering smaller statistical units, which can provide more detailed data that are closer to the O-D matrix zoning. In general, the use of smaller units reduces generalisation and provides more accuracy.

Sensitivity analysis allows to find the most suitable models for the local situation. In this way, uncertainty related to the choice of model can be reduced by acting on two aspects: input uncertainty and model uncertainty (Rasouli and Timmermans 2012). Input uncertainty originates from errors in input data. The VISUM model uses data from the household survey to produce the O-D matrices. Errors can occur in survey design (such as creating bias between response and non-response groups), survey data interpretation and coding. The literature suggests that a 5% population surveyed is sufficient to identify the travel demand on the basis of a household survey (Ziliaskopoulos and Mitsakis 2008). This study was covered only 0.31% coverage of the total population. However, the validation of the model against observed traffic data shows that the model produces a good result in estimating traffic at any given point, with a maximum of 6% differences.

The dispersion model did not take into account the high concentration of pollution on and along the roads. Areas further away from main roads, which are partially protected by housing rows, often experience lower concentrations of air pollutants. Consequently, models generalise certain aspects of reality. However, the use of models is necessary as the alternative is to base estimations on extensive and expensive personal exposure monitoring for hard-to-define representative groups of environmentally exposed residents (Jerrett and Finkelstein 2005). Moreover, models allow annual or bi-annual assessments to monitor the environmental impacts of development as well as the application in strategic environmental assessment.

As many monitoring sites may not be truly representative of the studied areas, all data was used, assuming a degree of representativeness. Better air quality monitoring due to transportation will contribute to a greater accuracy of the approach. The pollution concentration maps can help identifying proper locations for monitoring. Another source of uncertainty in this study is the variability in travel times, of congestion or the availability of seats on vehicles has not been taken into account. This is shown clearly in emission and dispersion models, where the models mostly produce a concentration lower than observed level of PM_{10}. Measurements at major street junctions show that PM_{10} concentration is much higher than modelled, showing that the air quality model mostly underestimates the concentration of PM_{10} as shown in chapter 3. Temporal variations of traffic patterns should be explicitly modelled, which was not considered in the current model.

There are also uncertainties in exposure assessment. In additional to providing insight on the level of exposure to air pollutants, the use of GIS allows sectioning the city into small sectors, each with their unique demography. The study assumes that the population density is homogeneous in each studied commune, due to the lack of more detailed data below the communal level. However, the population density is often unevenly spread. Along the main roads e.g. more populated neighbourhoods are found. This asserts the need to consolidate data collection for administrative purposes and for modelling purposes in the future.

In addition, the distribution of particles is not homogeneous but affected by traffic intensities and therefore the proximity to major roads increases health risks

(Hoek, Brunekreef, et al. 2002; Hoek, Meliefste, et al. 2002). In reality, each person is exposed differently to air pollution, depending on one's activities over space and time (Chiodo and Rolfe 2000; Fisher et al. 2002; Kunzli et al. 2000; Le Tertre et al. 2002; S Medina et al. 2005). However, this variability could not be taken into account in this study. Also, since pollutants vary within the commune, estimating of the number of people exposed to different levels around the mean annual concentrations of PM_{10} is the major task. The exposed population was calculated using a GIS-based approach that includes data on area and population density of the 52 communes and estimated PM_{10} concentrations using dispersion model. $PM_{2.5}$ concentrations were then calculated based on PM_{10} concentrations. The exposed population to a particular concentration of PM_{10} was calculated for the population group who are over 30-year-old [P_{30+}] by overlaying concentration map on population density map. The number of people exposed to each range of pollution concentration was calculated. That those people do not live on the first floor are exposed to lower pollution levels couldn't be taken into account due to the lack of detailed data. The use of a microscopic model will result in a better accuracy in calculating the variability.

5.3.3. Other approaches in HIA

The burden of disease is the impact of a health problem expressed in financial cost, mortality, morbidity, or other indicators. The overall disease burden is a measure of the gap between the current and the ideal health status, without disease and disability. Murray (1994) suggested to use disability-adjusted life years (DALYs) to measure the impact. DALY is used to quantify the burden of disease based on the calculation of the life time lost as a result premature mortality or living with a disability, normally in comparison with the life expectancy. One DALY can be thought of as one year of healthy life lost. These measures allow for comparison of disease burdens, and also have been used to forecast the possible impacts of health interventions. The environmental burden of disease is defined as the number of DALYs that can be attributed to environmental factors.

The use of DALY as a metric has gained mainstream attention since its conception in the WorldBank's World Development Report 1993: Investing in Health. The WHO also provided a set of detailed guidelines for measuring disease burden at the local or national level. DALY is increasingly popular in the field of public health and health impact assessment (HIA) as an approach to aggregate various metrics (such as mortality and morbidity). In addition, health burdens can be used to calculate the socio-economic burden in a cost-benefit analysis framework or can be useful in policy negotiations and decision - making. DALY relies on risk threshold, exposed population and severity. These data are commonly used in other health risk assessment methods. Therefore, it is possible to use DALY in complement with other methods to extend the range of risk assessment and to facilitate comparison of options and risk communication.

The major pitfall of this approach is that DALYs are often used in economic estimations, which put monetary values on human health. This necessitates value led choices. By doing so, the health of different people due to age, gender, and capabilities is not adequately considered. DALYs fail dealing with differences between individuals in a fair way (Anand and Hanson 1997). These authors argue that “similarity” or “generalisation” is unequal to “fairness” and “equity”, especially when DALY is used as an economic metric for resource allocation.

5.4. Opportunities and challenges to apply integrated modelling and GIS in HIA in Vietnam

Already today opportunities exist integrating HIA into the EIA report, as the Law on Prevention and Control of Infectious Diseases 2007 states that investment projects on the construction of industrial parks, urban centers, residential areas or infectious disease examination and treatment establishments can be executed only after their health impact assessment reports have been appraised by competent health agencies. Furthermore, article 17, Decree No. 29/2011/ND-CP adds that an EIA report aims assessing and predicting a project's impacts on natural conditions, natural environment, community and related socio-economic factors; community consultation results; and to propose measures to mitigate negative environmental impacts on the nature, public health and the relevant socio-economic aspects. However, health issues are only mentioned very general (for example mentioning of action “with the risk of illness") and inclined more to social health (such as population explosion, increases in social vices, traffic accidents, alcohol abuse, etc.). There is no specific mention of action plan to limit and overcome the health risks.

There is a need for integrating HIA into EIA as health risks should be studied to establish prevention and mitigations measures. Also, decision making should consider a wide array of aspects including economic, engineering, environmental, health and social issues.

Modelling and GIS is widespread in EIA. Environmental modelling is widely used to estimate the extent of environmental impacts resulting among others from the transport of pollutants in the atmosphere or in water. Air pollution models are popular and the use of both air monitoring stations and measurement campaigns to run the models are reported (Briggs et al. 2000; Safonov, Favrel, and Hecq 1999; Brzozowski 2006; Hung et al. 2010; Cheng et al. 2007). Since the middle of the 1990s, the Vietnam National Annual Environmental Status Reports and the corresponding city/provincial reports are periodically published. Modelling results have been used frequently to report on, amongst others, air quality and air pollution. The national reports are compiled using data drawn from the national environmental monitoring network, which monitors basic quality parameters for air, water, land, coasts, solid waste, noise, acid deposition, radioactivity and the indoor working environment. However, HIA has hardly been incorporated in these reports. Only possible impacts on the public health are regularly mentioned.

As modelling and GIS have already been used in EIA, environmental assessment and reporting, integrating modelling/GIS and HIA expanding the scope of such assessment and reporting is the logical next step. Impacts on human health due to environmental determinants are described for relevant environmental and development policies. Guidelines for EIA should be issued by the Ministry of Health and Ministry of Natural Resources and Environment and HIA must be performed by experts.

The first steps in facilitating this implementation have been realised. A series of training activities in the capacity building for HIA, and a pool of key trainers in HIA including focal staff in MoH and MONRE has been established. Awareness on HIA in healthcare and environ-mental staff at all levels has improved. Co-operation between MoH and MONRE in developing NEHAP has been materialised. Although necessary these efforts are insufficient to facilitate the implementation of the HIA process.

A number of challenges are necessary to address. The current environmental law system entails that the proponent of the project is responsible for initiating impact assessment studies. Public health authorities and health agencies should have an advisory role through out the process, from framing the important health issues during the scoping stage, and to review the statement of the possible health impacts within EIAs. Their participation in the process must be clearly defined. The involvement of the public in the process is minimal and hardly defined. The public should have an advisory role during the process. Therefore, they should actively participate during the HIA procedure. In addition, approaches should be developed to bring all health impacts together in a coherent analysis of total health burden, and make sure health is dealt with in the wider scope of EIA. Therefore, HIA practitioners should focus on extending health considerations within EIA from the current environmental health approach in order to include more health determinants in the assessment. Currently, health impact practitioners focus mostly on the physical health issues, especially on identifying and treating health problems. Collaborative work with other specialists in social and cultural impact assessment is needed to extend the scope of health outputs.

Health studies in Vietnam are to establish dose-response functions which correspond with the Vietnamese population. The choice of a dose-response relationship is one of the critical aspects of HIA. In this study long-term mortality was calculated using the relative risk (Kunzli et al. 2000) that is commonly used in HIA studies. However, considering the study focuses on the urban area, the combustion particles could cause relative risk up to 1.17 per 10 $\mu g/m^3$ increase of $PM_{2.5}$ (Jerrett et al. 2005). Therefore, the effects on mortality could have been underestimated. There are many other exposure-response coefficients available, but there is a great deal of differences of opinion, and additional studies are needed in order to determine which coefficient is the most indicated (Orru et al. 2009).

In addition, the baseline population and health data are vital determinants affecting HIA results Tainio et al. (2005) and Orru et al. (2009). The main cause of overestimation is the high baseline mortality rate (driven by external causes), which could influence the relative exposure impact. The baseline mortality rate is influenced by the lifestyle of the population as well as by other social and economic issues. Social issues include security or alcohol/drug uses, and socio-economic issues are about poverty and occupational safety. The impact of these aspects on the baseline mortality can be studied.

Another concern is the use of exposure data in combination with the assumed threshold level of health effects. Studies have shown that fine particulate matter can cause negative effects on concentrations below the current standards. In this study, mortality was calculated assuming that a threshold of 7.5 $\mu g/m^3$ is applied. If the calculation was based on a no-threshold effect, the number of attributable cases will be definitely higher.

Finally, the amount of time a person spends in residence area and abroad (work, studies, etc.) affects individual exposure, and was used in estimating transport flows. However, this data was not incorporated into exposure assessment, as they are no part of the exposure-response functions. This can be overcome by consolidating the process of data collection and storage between sectors and for different purposes, so that data can be reliably and consistently available in the future.

5.5. Relevance to Human Ecology

Environmental problems are often complex as people involved have different concerns and engage in different activities that interact with the environment and therefore move the problems in different directions. The interactions between the societal actors and the environment are the core of a field as "human ecology". Human ecology studies the interrelationships between humans and their environment. Within this framework, human ecology is a methodology as much as an area of research.

This research reflects the core content of a human ecological research, which deals with the interactions between the environment (air quality) and the human society (human health). As a research in human ecology, it entails distinctive characteristics. A most noticeable one is related to the transition from multidisciplinarity towards interdisciplinarity. Multidisciplinary research emerges when more than one discipline is involved in a study. The cooperation and coordination of disciplines at different levels and the subsequent combination of data and methodologies in a collective pool of knowledge and understanding of the problem leads to interdisciplinarity. This refers to integration of results of different disciplines and "emergent" results that can only be reached through integration. This study fits in the human ecological research in both contents and approach. The subject matter is relevant to human ecological research as it addresses both the studies of environmental components (air quality, pollution dispersion) and the human societal component (human environmental health).

This research directly helps with the implementation of the principles of Sustainable Development. Sustainable development is often seen as entailing three major components (economic, social and environmental), each of which must be "sustainable" before the whole system can achieve sustainability. By adding health issues in to the assessment, each of the three components will need to incorporate new elements. Economically, health impacts of air pollution will bring in additional health costs, which must be considered. From social perspective, equity within and between generations is the most important consideration in sustainable development. The research fosters this equity by making evident visible through the mapping of health impacts as different groups experience different levels of air pollution and therefore different health burdens. Finally, environmentally, the research will contribute to the assessment of different mobility scenarios through which a better choice can be made to reduce both environmental and health impacts.

In the case of Hai Phong, the research contributes to promote the application of Green City by merging urban ecology perspective and sustainability perspective. The Green City concerns urban centres that use clean energy and in an efficient way, that have sustainable transportation and built infrastructure, that conserve resources and reduce wastes. A green city is a healthier, more affordable, and more pleasant place to live. This research contributed to a discussion on policy recommendations for green growth in Vietnam and on the development of a model for a green port city in Hai

Phong in the framework of the national workshop on "Green Growth and Green Port City" organised by IUCN-MFF and the City of Hai Phong in March 2014.

Besides benefiting from the Human Ecological research approach, this research also contributes to the advance of the field in several ways. First of all, this research provides an example of the integration process that is needed to bring forward interdisciplinary characteristics of a human ecology study. In this process, coordination is proved crucial to organise research activities and to produce integrated coherent results.

Second, its use of modelling and GIS as a medium for data and methodological integration shows GIS is a useful medium for the integration of natural and social sciences. The strength of this approach lies in the fact that GIS is a powerful spatial analysis and visualisation tool with advantages options in collecting, analysing and presenting data and results, especially for groups such as policy-makers and stakeholders. It is very flexible medium for its modulation ability. It can contain various layers of data from different disciplines (physical, geographical, environmental, social, etc.), to produce interdisciplinary results. Different assessment modules can be integrated and presented. As a result, comparison of options can be produced clearly and visually. In this study, it combines pollution maps and population maps to produce exposure map. Adding health dose-response functions, health impact maps can be produced.

Finally, the results produced by this integration provide an added value in decision-making. For each traffic scenario, a corresponding health impact scenario can be produced. This result added to the environmental impact assessment results and provides decision-makers an addition criterion for evaluating different development options. This type of ability is especially important in SEA, where comparisons of options are based on a multitude of studies. The ability of models to provide forecasts (or scenarios) can contribute significantly to SEA. In combination with the ability of GIS to integrate different disciplines, modelling-GIS coupling will be useful in offering an interdisciplinary approach in quantitative assessment of current situation and of future scenarios, which are the core of SEA.

5.6. Conclusions

Health is the result not only of individual characteristics and lifestyle but also of the socio-economic or physical environment. These ‘health determinants’ may affect people’s health directly or indirectly. Therefore, decisions in all policy areas including economic development, infrastructure, industries, agriculture, etc. will affect people’s health. This is mediated by policies, strategies and plans and programmes and projects within these policy areas.

HIA allows identifying the future health consequences of a proposed action using a combination of procedures, methods and tools by which a policy, program or project may be assessed as to its potential effects on the health of a population, and the incidence of these effects within the population (Gothenburg consensus paper 1999 (European Centre for Health Policy 1999)). As HIA is a ‘combination of procedures, methods and tools’, different combinations of methods can be developed as there is no “one and only” method. Secondly, HIA is about predicting ‘potential effects’ rather than evaluating effects that have already occurred. HIA also shows the distribution of effects within the population and does not only provide with the sum of effects.

Currently, health is often included within environmental assessment but this may not include the full range of potential health impacts. Moreover guidelines are often limited or lacking. Policy makers base decision on a growing number of impact assessments, including economic assessment, environmental impact assessment, sustainability assessment, and strategic impact assessment. There is a need to reconcile and combine these various assessment processes into an integrated assessment, which includes environment, health, equality, economic and other impacts as appropriate.

The use of modeling and GIS as a common platform for different assessments to be integrated is gaining momentum, as it proves to have many strengths in using all available data in different units and forms and allows handling large amount of data. The use of models and GIS in a health risk assessment, from a decision making point of view, can reduce the processing/waiting time, in comparison to the in depth personal exposure study with better accuracy than using purely monitoring data and health statistics. The use of models and GIS allows to understand the links between air quality and health outcomes visually and is therefore useful in the decision-making process on urban planning and development of the Hai Phong urban area.

A number of improvements can be made to further advance the integration. An improved integration programme of the data will facilitate the application of integrated models in policy-making. Data on mobility survey, environmental monitoring and measuring must be standardised and legalised. Various traffic models, as well as emission and dispersion models should be tested more attention should be given to uncertainty and sensitivity. Other health effects of transport, such as those caused by noise and other pollutants can also be incorporated in the integrated model to producing more information for planners, policy makers and other stakeholders.

Although there is no single 'blueprint' for HIA, key principles to HIA are defined, such its systematic character; involvement of the decision-makers and affected communities, taking into account local factors, use evidence and methods appropriate to the impacts identified and the importance and scope of the policy, and make practical recommendations. GIS and modelling can enhance the compliance to those principles. Despite the uncertainties, this study highlights the need to consider integrated approaches when preparing development plans and a strategy to build a systematic assessment framework by further development of different modules of the models to obtain better estimation accuracy.

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Annex: Health Survey Questionnaire

HOUSEHOLD ID: ________________

1. Home address: ....

2. Distance to the main road: .... m.

3. Number of years living at this address: _______ years

4. Number of years living in Hai Phong area: _____ years

5. The household composition: ____________ members

6. Average monthly income of the household: ___________________ VND/month

Among people with incomes:

Highest income in the household: ___________________ VND/month
Lowest income in the household: ___________________ VND/month

7. House type and ownership

Type	
House	
Apartment	
Other	
Non regular	
Characteristics	
Number of bed rooms	
Household size (square meters)	m^2

Ownership Status	
Private	
Rent (indicate monthly rent in VND)	VND
Free of rent, Other	

8. Assets of the households

	Item	**Quantity**
1.	Television	
2.	Radio–cassette/CD Player/MP3 Player	
3.	Video CD/DVD player	
4.	Bike cycle	

	Item	**Quantity**
5.	Motorbike	
6.	Car	
7.	Minibus	
8.	Van	

For each member of this household, please complete a separate **QUESTIONNAIRE 02 – INDIVIDUAL SURVEY**

HOUSEHOLD ID: ________________

Individual ID: ________________

Information on the each member of the household

1. Name: ____

2. Sex: ____

3. Age: ____

4. Education level: ____

5. Occupation: ____

6. Civil status: ____

7. Duration of residency in this area: ___________ years

8. Previous location of residency: _______________________________________

Medical history (for each member of the household)

General Medical History

9. Have you ever worked full time (30 hours per week or more) for 6 months or more?

☐ Yes ☐ No

10. Have you ever worked for a year or more in any <u>dusty job</u>?

☐ Yes ☐ No

If Yes,

→ Specify job/industry: _________________________

→ Total years worked in the industry: _____ years

→ How was the dust exposure? ☐ Mild ☐ Moderate ☐ Severe

11. Have you ever been exposed to gas or chemical fumes in your work?

☐ Yes ☐ No

If Yes:

→ Specify job/industry: _________________________

→ Total years worked in this industry: ____ years

→ How was the dust exposure? ☐ Mild ☐ Moderate ☐ Severe

12. What has been your usual occupation or job -- the one you have worked at the longest?

1. Job-occupation: ____

2. Number of years employed in this occupation:______________________

3. Position-job title: ____

4. Business, field, or industry: _____________________________________

13. Have you ever smoked cigarettes? (NO means less than 1 cigarette a day for 1 year.

☐ Yes ☐ No

14. Do you now smoke cigarettes (as of 1 month ago)?

☐ Yes ☐ No

15. How old were you when you first started regular cigarette smoking?

Age in years: _______

16. If you have stopped smoking cigarettes completely, how old were you when you stopped?

Age in years: _______

17. How many cigarettes do you smoke per day now?

___ Cigarettes/day

18. On the average of the entire time you smoked, how many cigarettes did you smoke per day?

___ Cigarettes/day

19. Do or did you inhale the cigarette smoke?

☐ Does not apply
☐ Not at all
☐ Slightly
☐ Moderately
☐ Deeply

20. Have you ever smoked a pipe regularly? (YES means more than 12 oz tobacco in a lifetime).

☐ Yes ☐ No

21. How old were you when you started to smoke a pipe regularly?

Age in years: _____

22. If you have stopped smoking a pipe completely, how old were you when you stopped?

Age stopped: ____

23. On the average over the entire time you smoked a pipe, how much pipe tobacco did you smoke per week?

____ gr per week

24. How much pipe tobacco are you smoking now?

___ gr per week

25. Do or did you inhale the pipe smoke?

☐ Never smoked

☐ Not at all

☐ Slightly

☐ Moderately

☐ Deeply

Personal Medical History Related To Respiratory Diseases/Illnesses

Acute Respiratory Symptoms

These questions pertain mainly to your acute illness. Please answer yes or no if possible. If a question does not appear to be applicable to you, check the does not apply space. If you are in doubt about whether your answer is “yes” or “no”, record “no”.

26. COUGH

a. Do you usually have a cough? (Count a cough with first smoke or on first going out-of-doors. Exclude clearing of throat).

☐ Yes ☐ No

b. Do you usually cough as much as 4 to 6 times a day, 4 or more days out of the week?

☐ Yes ☐ No

c. Do you usually cough at all on getting up, or first thing in the morning?

☐ Yes ☐ No

d. Do you usually cough at all during the rest of the day or at night?

☐ Yes ☐ No

IF YES TO ANY OF THE ABOVE (a, b, c, OR d), ANSWER THE FOLLOWING:

IF NO TO ALL, CHECK “DOES NOT APPLY” AND SKIP TO 36a.

e. Do you usually cough like this on most days for 5 consecutive months or more during the year?

☐ Yes ☐ No ☐ Does not apply

f. For how many years have you had this cough?

Number of years: ____________________

27. PHLEGM

a. Do you usually bring up phlegm from your chest? (Count phlegm with the first smoke or on first going out-of-doors. Exclude phlegm from the nose. Count swallowed phlegm) [If no, skip to 36c.]

☐ Yes ☐ No

b. Do you usually bring up phlegm like this as much as twice a day, 4 or more days out of the week?

☐ Yes ☐ No

c. Do you usually bring up phlegm at all on getting up or first thing in the morning?

☐ Yes ☐ No

d. Do you usually bring up phlegm at all during the rest of the day or at night?

☐ Yes ☐ No

IF YES TO ANY OF THE ABOVE (A, B, C, OR D), ANSWER THE FOLLOWING QUESTION E AND F:

IF NO TO ALL, CHECK DOES NOT APPLY AND SKIP TO 36.

e. Do you bring up phlegm like this on most days for 3 consecutive months or more during the year?

☐ Yes ☐ No ☐ Does not apply

f. For how many years have you had trouble with phlegm?

Number of years: ____________________

28. EPISODES OF COUGH AND PHLEGM

a. Have you had periods or episodes of (increased*) cough and phelgm lasting for 3 weeks or more each year? *(For individuals who usually have cough and/or phlegm)

☐ Yes ☐ No

IF YES:

b. For how long have you had at least 1 such episode per year? Number of years: ____________________

29. WHEEZING

a. Does your chest ever sound wheezy or whistling:

1. When you have a cold?
☐ Yes ☐ No

2. Occasionally apart from colds?
☐ Yes ☐ No

3. Most days or nights?
☐ Yes ☐ No

IF YES TO ANY OF 1, 2, OR 3 IN a:

b. For how many years has this been present?
Number of years: ____________________

c. Have you ever had an ATTACK of wheezing has made you feel short of breath? For how many years has this been present?
☐ Yes ☐ No

IF YES TO c:

d. How old were you when you had your first such attack?
Age in years such attack? __________________

e. Have you had 2 or more such episodes?
☐ Yes ☐ No ☐ I don't know

f. Have you ever required medicine or treatment for the(se) attack(s)?
☐ Yes ☐ No ☐ I don't know

30. SHORTNESS OF BREATH

a. Are you troubled by shortness of breath when hurrying on the level or walking up a slight hill?
☐ Yes ☐ No

IF YES TO a:

b. Do you have to walk slower than people of your age on level because of breathlessness?
☐ Yes ☐ No ☐ I don't know

c. Do you ever have to stop for breath when walking at your own pace on the level?
☐ Yes ☐ No ☐ I don't know

d. Do you ever have to stop for breath after walking about 100 m (or after a few minutes) on the level?

☐ Yes ☐ No ☐ I don’t know

e. Are you too breathless to leave the house or breathless on dressing or undressing?

☐ Yes ☐ No ☐ I don’t know

31. Did you have any lung trouble before the age of 16?

☐ Yes ☐ No ☐ I don’t know

Chronic Respiratory Symptoms

These questions pertain mainly to your ***chronic illness*** *(last at least 3 months). Please answer yes or no if possible. If a question does not appear to be applicable to you, check the does not apply space. If you are in doubt about whether your answer is “yes” or “no”, record “no”.*

32. Have you ever had any of the following:

a. Attacks of Bronchitis?

☐ Yes ☐ No

IF YES:

1. Was it confirmed by a doctor?

☐ Yes ☐ No ☐ I don’t know

2. At what age was your first attack?

Age in year: ___________ ☐ I don’t know

b. Pneumonia (include bronchopneumonia)?

☐ Yes ☐ No

IF YES:

1. Was it confirmed by a doctor?

☐ Yes ☐ No

2. At what age did you first have it?

Age in year: ___________ ☐ I don’t know

c. Hayfever?

☐ Yes ☐ No

IF YES:

1. Was it confirmed by a doctor?
☐ Yes ☐ No

2. At what age did it start?
Age in year: ___________ ☐ I don't know

33. Have you ever had chronic bronchitis?
☐ Yes ☐ No

IF YES:

1. Do you still have it?
☐ Yes ☐ No ☐ I don't know

2. Was it confirmed by a doctor?
☐ Yes ☐ No ☐ I don't know

3. At what age did it start?
Age in year: ___________ ☐ I don't know

34. Have you ever had emphysema?
☐ Yes ☐ No

IF YES:

1. Do you still have it?
☐ Yes ☐ No ☐ I don't know

2. Was it confirmed by a doctor?
☐ Yes ☐ No ☐ I don't know

3. At what age did it start?
Age in year: ___________ ☐ I don't know

35. Have you ever had asthma?
☐ Yes ☐ No

IF YES:

1. Do you still have it?
☐ Yes ☐ No ☐ I don't know

2. Was it confirmed by a doctor?
☐ Yes ☐ No ☐ I don't know

3. At what age did it start?

Age in year: ___________ ☐ I don't know

4. If you no longer have it, at what age did it stop? Age in year: __________

36. Have you ever had:

a. Any other chest illnesses?

☐ Yes ☐ No

If yes, please specify:

____

____

b. Any chest operations?

☐ Yes ☐ No

If yes, please specify:

____

____

c. Any chest injuries?

☐ Yes ☐ No

If yes, please specify:

____

____

37. Has doctor ever told you that you had heart trouble?

☐ Yes ☐ No

IF YES:

Have you ever had treatment for heart trouble in the past 10 years?

☐ Yes ☐ No

38. Has a doctor ever told you that you have high blood pressure?

☐ Yes ☐ No

IF YES:

Have you had any treatment for high blood pressure (hypertension) in the past 10 years?

☐ Yes ☐ No

39. In the **last 2 weeks**, do you have any of the following symptoms?

Symptoms	**YES**		**NO**
	Often	**Occasionally**	
Eyes			
- Irritation			
- Watery eyes			
- Dryness			
- Soreness			
- Burning feeling			
Nose			
- Irritation			
- Running nose			
Throat			
- Irritation/itchy			
- Sneeze			
- Dry cough			
- Sore throat			
- Difficulty in breathing			
- Shortness of breath			
Skin			

Symptoms	**YES**		**NO**
	Often	**Occasionally**	
- Dry skin/lips			
- Skin rash (hands/feet)			
- Skin rash (face)			
- Skin rash (body)			
- Itchy (hands/feet)			
- Itchy (face)			
- Itchy (body)			
Other symptoms			
- Headache			
- Chest tightness			
- Drowsiness			
- Nausea			
- Unnatural thirsty			
- Loss of appetite			
- Chills			
- Lethargy			
- Fatigue			
- Loss of concentration			
- Sleeping problems			
- Stress			

Medical expenses

REASONS (name the diseases/illnesses)	**Last year expenses** (in VND)				Remarks
	Visit to doctor/physician	Hopitalisation	Buy medication	Others	
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					