Hamilton's Air Quality: Status and Expected

An Inquiry Submitted by

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Abstract:

Airborne pollutants can become hazards to community's health and the natural environment when concentrations become elevated. In this context, this study sheds light on the current status of Hamilton's air quality and provides a brief background and insight into the most substantial issues related to this topic. The inquiry mainly endeavors to answer the following questions: Why should Hamilton's residents be concerned about air quality? Is Hamilton's air clean? What are measures taken to keep Hamilton's air safe?

In order to frame a clear picture of the discussion, this study explains why the City is chosen for this inquiry and summarizes both pollution emission sources and air pollutants observed within the City. Also, this research examines the health effects of air pollutants and focuses on the importance of communication tools by which people can be informed of air quality. The impacts of Hamilton's atmospheric and geographic properties on its local air are discussed. This study concludes with the most prominent measures, policies and strategies that effectively reduce emissions of air pollution and improve Hamilton's air quality.

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1. Introduction

Air quality is of considerable importance because people cannot avoid breathing in the air around them. In addition to sustaining life, air plays a vital role in many functions that are best performed when air quality is high (Environment Canada, 2010a). Air quality monitoring has been focused in densely populated metropolitan areas, especially in industrialized countries where environmental regulations are fairly strict or existent (Molina and Molina, 2004).

The problem of air pollution has grown steadily since the Industrial Revolution due to four major factors that have exacerbated air pollution over the years: burgeoning industrialization, rising traffic, rapid economic growth, and higher levels of energy consumption (Romieu, 1998). However, undesirable levels of air pollution have found in urban areas in developed countries (Molina and Molina, 2004). The World Health Organization (WHO) standards for the key air contaminants are regularly exceeded in many major cities (Romieu, 1998; Schwela, 2000), and many urban cities throughout the world have reached alarming levels (Wallace et al, 2009). Accordingly, people who live in cities near the sources of pollution, in particular cities with mixed residential and industrial activities, should be concerned because they might expose to a greater amount of pollutants coming from different sources (Elliott et al, 1999).

On the other hand, many studies have focused on estimating the relationships between air pollution and health, confirming that there is ample evidence and a relative association between exposure to poor air quality and the escalating morbidity rate, such as respiratory and cardiovascular diseases (Jerrett and Sahsorovglou, 2003; Brook et al, 2004; Canadian Medical Association, 2008).

In order to protect human health, a great deal of strategies and a combination of policies are set to reduce air pollution and improve air quality. Research shows that urban cities can efficiently manage their air quality problems through effective measures such as implementation of new sustainable technologies, development of effective environmental regulations, communication with the public regarding air quality concerns, etc. (Molina and Molina, 2004; Neidell, 2004).

2. Why Hamilton?

Hamilton is a medium-sized city combining between industrial and residential activities with a population reaches approximately 504,559 (Statistics Canada, 2006). The city is located on the west shore of Lake Ontario (43.3˚ N, 79.9˚ W) and is home to an enormous number of industrial sectors ranging from iron and steel companies, chemical productions and several recycling facilities (Figure 1) (Wallace et al, 2009). The City has a wide range of emitters, including the two largest steel mills in Canada, and has experienced high air pollution levels in the past, sometimes exceeding prescribed air quality criteria (HAQI, 1997; Jerrett and Sahsorovglou, 2003; Corr, 2006; Pouliou et al, 2008).

The evaluation of air quality and emission sources in Hamilton has always been a big challenge in view of impacts of a combination of factors that do not coincide in other communities in southern Ontario (Corr, 2006, 2008; Sahsuvaroglu and Jerrett, 2007; Wallace et al, 2009, 2010a.). These factors somehow participate in the formation of a marked gradient in air pollutant exposures, as follows:

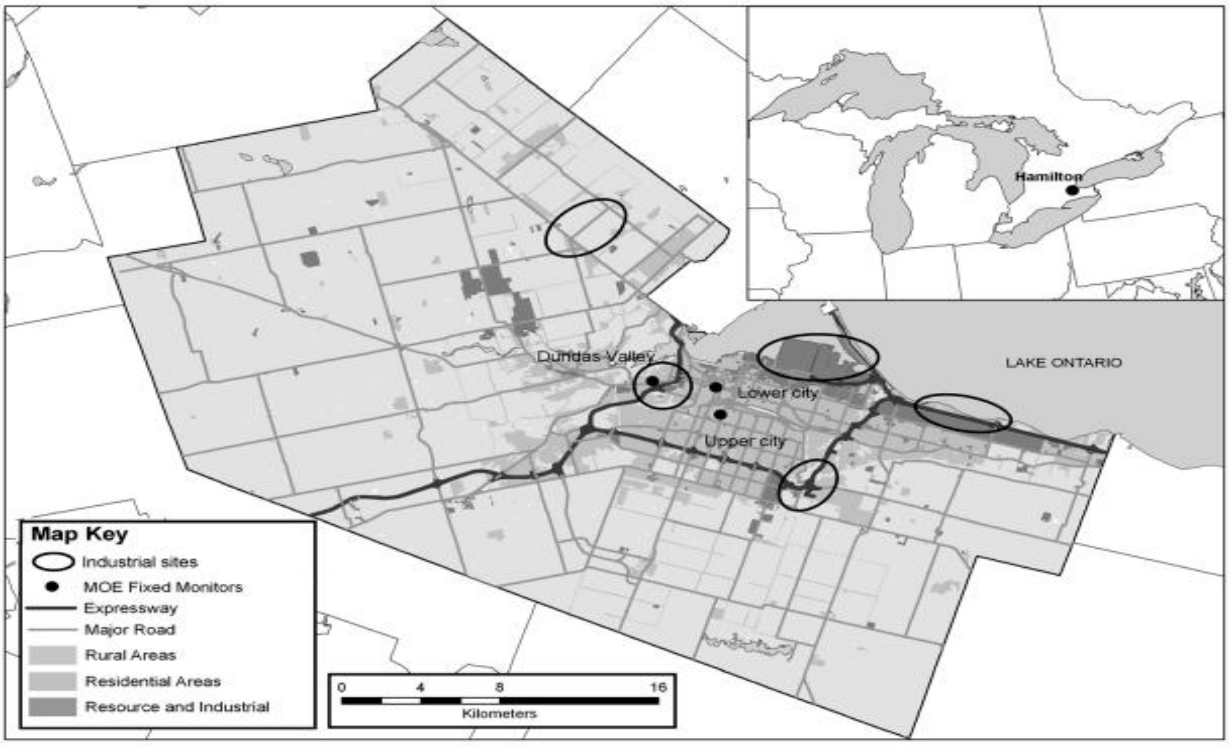

Figure 1: City of Hamilton: Major Roads, Residential and Industrial Areas (Wallace et al, 2009).

1. The close proximity of the heavy industrial facilities to each other, which are situated on a harbour in the northeastern section of the City.
2. The complexity of meteorological conditions due to winds coming from the southwest and northeast as well as thermal inversions that may cause pollutant build-ups, particularly in the lower City.
3. The presence of the Niagara escarpment that separates the City into the lower and upper areas with several satellite villages incorporated in the larger urban area. This escarpment may act as a downwind barrier, trapping pollution.
4. The presence of various types of transportation modes as the four major highways, railways and cargo corridors of Hamilton's Harbour. These roads in and around the City are heavily used by local residents, commuters who pass through the City and long-distance traffic.

5. Transboundary or long-range transport of air pollution coming from the industrialized areas in the mid-western United States leads to increase levels of some air pollutants in the City (Clean Air Hamilton, 2011).

Building on aforementioned reasons, Hamilton provides a good example to explore the local air quality, relevant concerns and ways of addressing the challenges.

3. Types of Air Pollutants

Given that there are different types of air pollutants, each contaminant has specific characteristics in regard to chemical structure, chemical reactions, sources, persistence, ability to travel, and health effects (Table 1) (Clean Air Hamilton, 2010). In general, air pollutants are divided into four main categories: criteria air contaminants (CACs), persistent organic pollutants (POPs), heavy metals and toxics (Environment Canada, 2010a).

Table 1: Air Pollutants, Sources, and Pollutant Lifetimes in the Atmosphere (Clean Air Hamilton, 2010).

Air Pollutant	Sources	Approx. Lifetime in the Atmosphere
Nitrogen oxides (NO_x)	Burning fossil fuels for transportation and building heating/cooling	A few days
Sulphur dioxide/sulphur oxides (SO_2/SO_x)	Burning sulphur-containing fossil fuels for transportation and industrial processes	A few days
Particulate material ($PM_{2.5}$ and PM_{10})	Primary PM emitted directly as dust, carbon from fossil fuels. Secondary PM arises from reactions of SO_2, NO_x, NH_3 and VOCs in the atmosphere.	Up to 10 days
Carbon monoxide (CO)	Burning fossil fuels for transportation	A few months
Tropospheric ozone (O_3)	Product resulting from reactions between NOx, VOCs, CO, CH_4, oxygen and sunlight in the atmosphere	Hours to days
Volatile organic compounds (VOCs) and hazardous air pollutants (HAPs)	Industrial process emissions; solvent use (both home and industrial)	A few days
Methane (CH_4)	Livestock farming Landfill/Waste Management	12 years
Black carbon (BC) and organic carbon (OC)	Burning wood or biomass; burning fossil fuels	About a week
Ammonia (NH_3)	Livestock farming and use of fertilizers	A few days

However, Jerrett and Sahsorovglou (2003) have identified five major pollutants that cause a number of premature deaths and hospital admissions in Hamilton each year. Those contaminants included carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), particulate matter (PM) and tropospheric ozone (O_3) or ground-level ozone (GLO).

The emission sources of different air contaminants vary. For instance, the production of SO_2, oxides of nitrogen (NO_x) and PM is a consequence of combustion of fossil fuels in stationary sources, including nitrate and sulphate aerosols combined in the air following gas to particle conversion. Further, petrol-fuelled motor vehicles are the principal sources of NO_x and CO, whereas diesel-powered engines emit significant quantities of SO_2, NO_x and PM (Romieu, 1998).

PM is usually arising from multiple sources as soil, smoke, pollens, soot, sea salt, vehicles and fugitive dusts. PM is sometimes referred as Total Suspended Particulate matter (TSP) that involves different particulate types in size. The most prominent types of PM are inhalable PM10[†], and respirable $PM_{2.5}$[‡] that makes up about 60% of the PM_{10} in the air (Clean Air Hamilton, 2010). The origins of respirable $PM_{2.5}$ include anthropogenic combustion sources, particularly vehicular emissions, whereas the origins of PM_{10} include re-suspended road dusts and dusts resulted from unpaved industrial work sites (Abelsohn et al, 2002; Newbold, 2009; Guo et al, 2010). In Hamilton, fugitive dusts are identified as a significant source of airborne PM that originate from non-point sources such as road dusts, industrial dusts, construction operations dusts, agricultural dusts, etc. In the past, fugitive dusts and road dusts have been deemed as nuisance dusts and an aesthetic problem, but recently they are regarded as a concern for human health (Clean Air Hamilton, 2011).

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† PM_{10} is airborne particles with a diameter of 10 µm.
‡$PM_{2.5}$ is airborne particles with a diameter of 2.5 µm.

Moreover, CO, NO_x and SO_2 are considered primary contaminants, while GLO is regarded a secondary pollutant and photochemical oxidant, which is formed in the lower atmosphere from NO_x and volatile organic compounds (VOCs) in the presence of sunlight. In Canada, high levels of GLO typically occur from May until September and from morning to early evening (Clean Air Hamilton, 2011). The high concentrations of GLO observed in Hamilton is caused by the emissions coming from the US Midwest; which arrives in southern Ontario via long-range transport from a number of US states. It is worth mentioning that there is an increasing trend regarding the GLO over the past decade because of transboundary air pollution from the US. (Clean Air Hamilton, 2011).

In addition to producing GLO, NO_x and VOCs can react, under the influence of sunlight to generate a complex mixture of chemical products known as smog. GLO forms one of the key constituents of smog, as well as PM (Clean Air Hamilton, 2006). In Hamilton, smog levels may elevate in the summer months due to high ozone levels affected by regional and long-range pollution sources wherein the U.S. accounts for nearly half of Ontario's smog. In return, smog concentrations may increase in the spring and fall months because of high levels of PM impacted by local pollution sources (Clean Air Hamilton, 2008).

A further consideration, the combustion of fossil fuels is the most important link between air pollution and climate change; and air pollutants impact climate change because many of them have atmospheric warming or cooling effects, more specifically black carbon and GLO (Reid, 2007; Ramanathan and Carmichael, 2008).

4. Emission Sources of Air Pollution

Air pollutants can come from diverse sources such as transportation, fossil fuels, electricity generation, iron and steel production, agriculture, residential, transboundary air movements, commercial products and so forth (Romieu, 1998).

However, the collection of an accurate and current data on emission sources in Hamilton is a great challenge because not all emission sources are reported accurately and not all emitters are required to report their emissions to Environment Canada's National Pollutant Release Inventory (NPRI) (Clean Air Hamilton, 2008). Nevertheless, the available emissions inventory data from the NPRI has demonstrated that the main emission sources are transportation, open sources and industries (Figure 2). More specifically, the transportation sector is the leading source of CO, NO_x and VOCs emissions, while the open sources (i.e. road dusts, construction activities and fireplaces) are the primary cause of $PM_{2.5}$ and PM_{10} emissions; and the industrial sector is the leading source of SO_2, which accounts for about 90% of SO_2 emissions in the City. By the light of this emissions data, it seems that CO is the principal contaminant from point sources, at 226,021 tonnes, followed by PM_{10} at 74,676 tonnes, NO_x at 34,400 tonnes and VOC at 22,287 tonnes (Table 2).

In addition to the above information, the NPRI inventory data has shown that there are five well-defined geographic areas that represented emission sources of air pollution in the greater Hamilton area. These areas are separate industrial aggregates in Flamborough/Waterdown (aggregates), East Mountain (aggregates), West Hamilton/Frid (mixed industrial and university), Northeast Industrial Area (heavy and mixed industrial) and Stoney Creek (mixed industrial and aggregates) (Figure 3) (Corr, 2006).

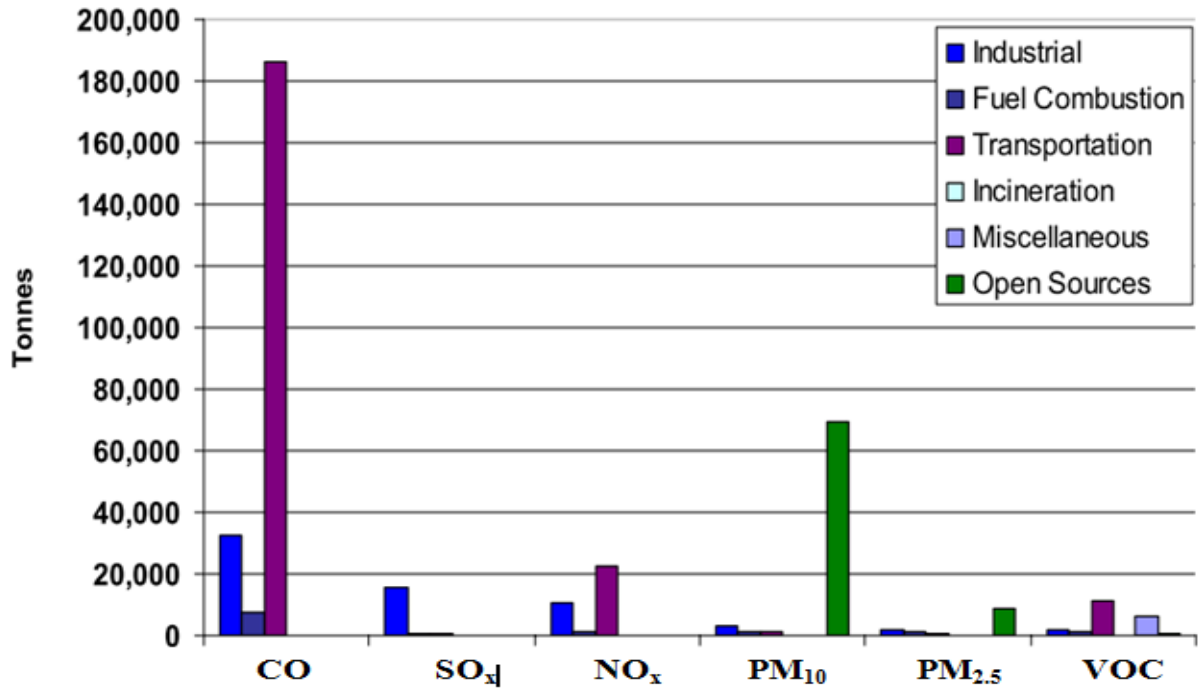


Figure 2: Total Point Source Emissions by Pollutant in Hamilton 2006 (Clean Air Hamilton, 2010).

Table 2: Total Point Source Emissions by Source in Hamilton 2006 (Clean Air Hamilton, 2010).

Source Category	CO	PM_{10}	NO_x	VOC	SO_x	$PM_{2.5}$
Transportation	186278	1017	22230	11501	417	1017
Industrial	32226	2934	10610	2175	15485	2084
Fuel Combustion	7387	1135	1513	1498	428	1119
Incineration	39	0	11	7	24	0
Miscellaneous	37	138	0	6495	0	138
Open Sources	54	69452	36	611	19	8917
Total Tonnes	226021	74676	34400	22287	16373	13062

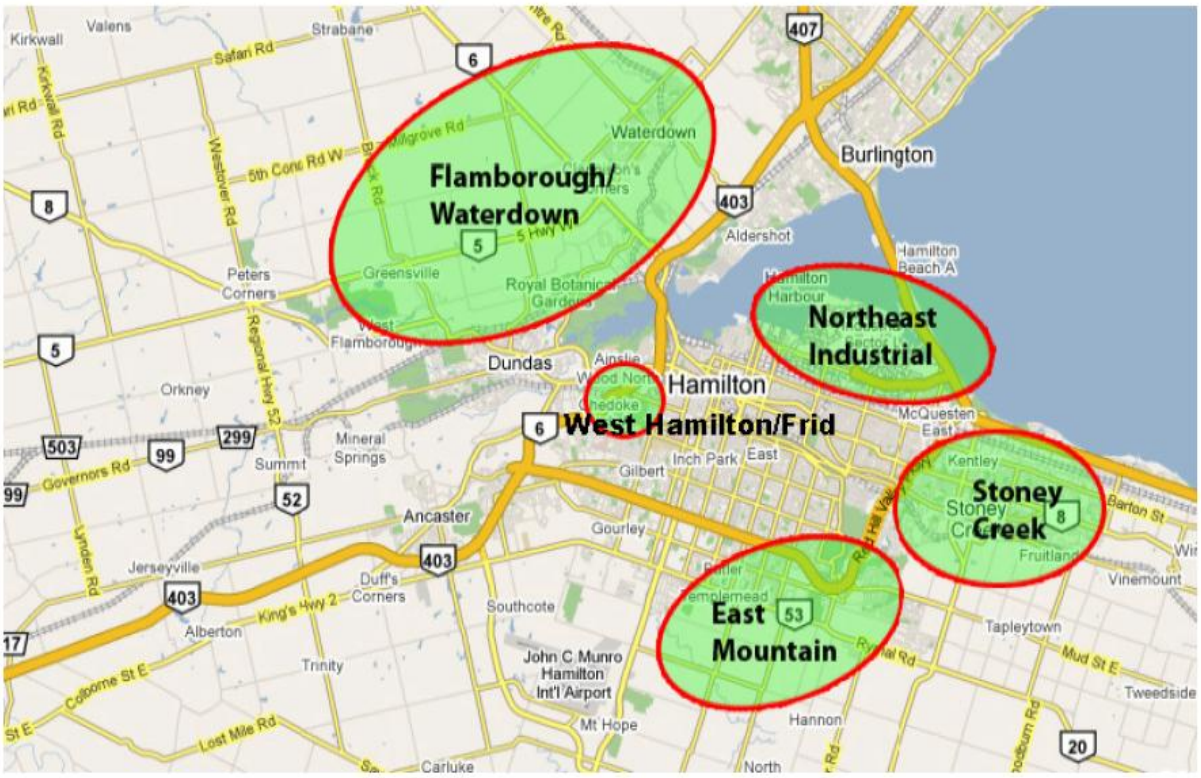


Figure 3: Industrial Emission Sources in the Greater Hamilton Area (Corr, 2006).

5. Health Effects of Air Pollutants

A lot of studies have established links between air quality levels and a variety of health outcomes. Recent surveys are trying to better understand and quantify the effects on a range of targeted health risks and their association with given air pollutants (Ontario Medical Association, 2005). It was proven that poor air quality can be especially harmful to young children and seniors who are much more susceptible to the adverse health impacts of poor air quality, as well as those with certain pre-existing medical conditions (Health Canada, 2001; Filleul et al, 2003; Finkelstein et al, 2003)

Research has indicated that air pollutants can cause a variety of health problems, in particular respiratory disorders like asthma, coughing, wheezing, bronchitis, lung damage,

reduced lung functions (Kelly and Fussel, 2011), and even lung cancer (Vineis and Husgafvel-Pursiainen, 2005). More importantly, several studies have reported significant associations between air pollution and mortality as well as between air pollution and morbidity due to respiratory diseases (Filleul et al, 2003; Finkelstein et al, 2004; Sahsuvaroglu and Jerrett, 2007; Neupane et al, 2010).

However, Jerrett and Sahsorovglou (2003) have illustrated that there is a well-established relationship between exposure to air pollution and related mortality. The researchers have also observed that there are five key air contaminants account for approximately 100 premature deaths and 620 hospital admissions each year in Hamilton (Figure 4), so that cardiovascular admissions are the leading health impact of these pollutants; and O_3 is the first cause followed by NO_2 (Figure 5).

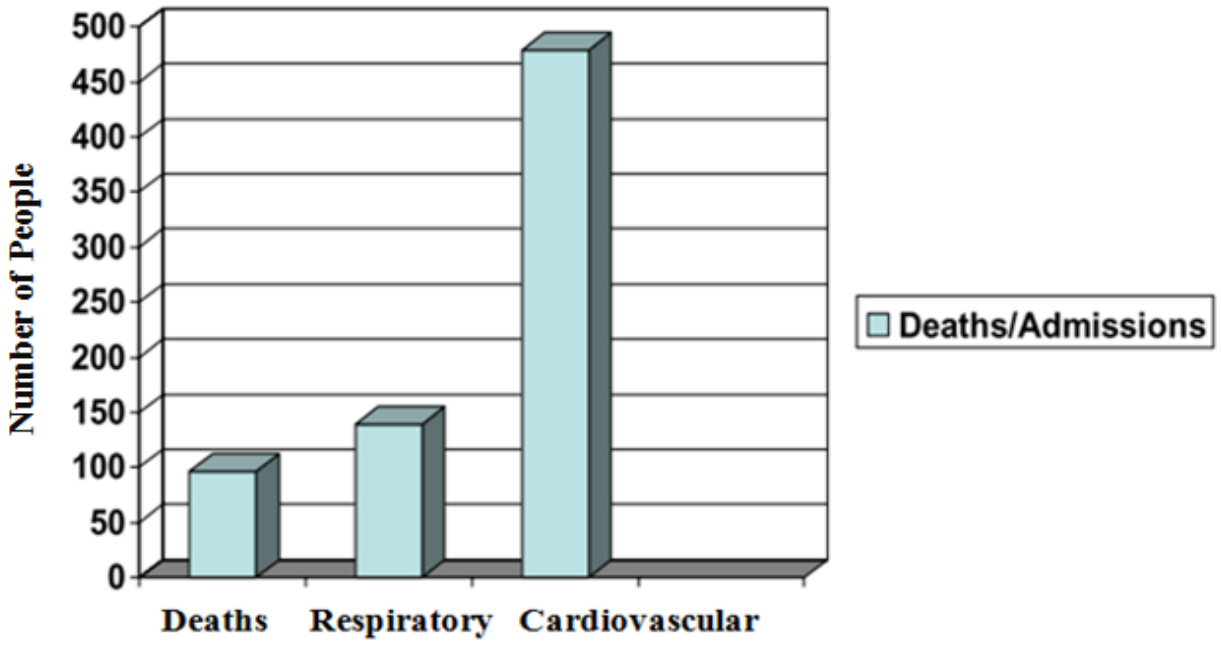


Figure 4: Annual Health Impacts of Air Pollution in Hamilton (Jerrett and Sahsorovglou, 2003).

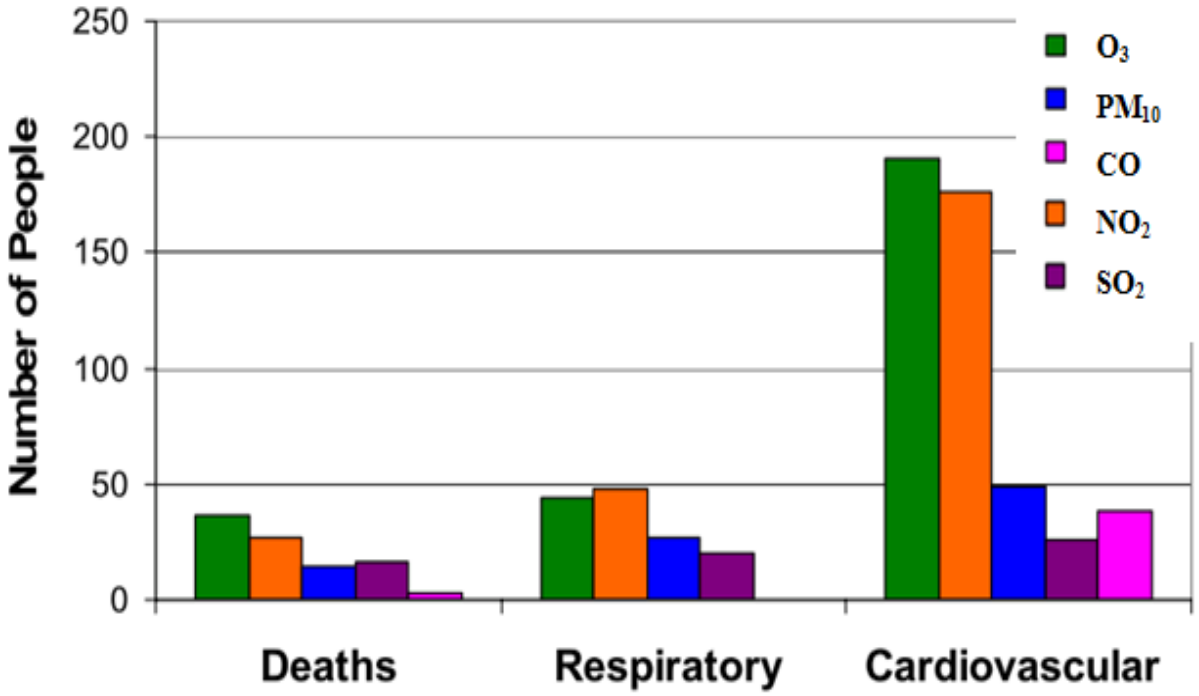


Figure 5: Annual Health Effects by Pollutant in Hamilton (Jerrett and Sahsorovglou, 2003).

Furthermore, Ontario Medical Association has elucidated that respiratory diseases attributable to air pollution, primarily O_3 and PM, contribute to 1925 deaths, 9807 hospital admissions, 13146 emergency room visits and approximately 46 million sick-days, costing more than a billion Canadian dollars (Ontario Medical Association, 2000, 2005). According to the previous studies, it was included that mortality is the only tip of the pyramid of health outcomes, and there are escalating numbers of less severe health outcomes as moving down the pyramid (Figure 6) (Corr, 2008).

Recent research findings suggest that $PM_{2.5}$ is more strongly related to cardiovascular disease (Laumbach and Wood, 2010), whereas PM_{10} and SO_2 is more closely linked with the risk of childhood asthma (Pouliou et al, 2008).

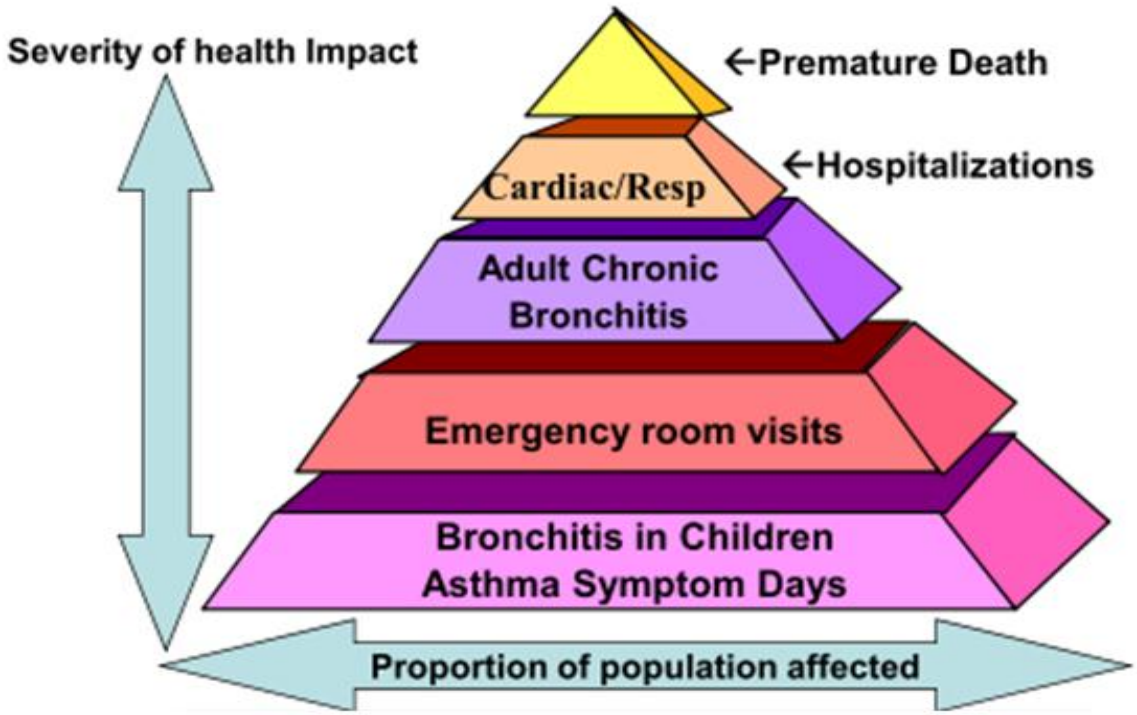


Figure 6: Pyramid of Health Effects Attributable to Air Pollution (Corr, 2008).

Additionally, Hamilton Public Health Services has reported that exposure to PM_{10} can attenuate immunological responses, resulting in higher rates of respiratory infections, whereas $PM_{2.5}$ can lower birth weights in newborns (Hamilton Public Health Services, 2009). One recent study found a stronger association between $PM_{2.5}$ and cardiovascular disease when the constituents of the PM are organic carbon or sulphates (Haynes, 2010). As well, Newbold (2009) has elucidated that carbon-based PM may also carry carcinogenic chemicals like benzo[a]pyrene (BaP). In very recent studies, Wallace et al (2010b, 2010c, 2011) have found that patients with airway diseases, living close to a highway or main road were associated with neutrophilic bronchitis, an increased risk of asthma diagnosis, asthma exacerbations and lower lung function.

6. Fixed Air Monitoring

For many years, the Ontario Ministry of the Environment (MOE) and Environment Canada carried out ambient and point source air quality monitoring in Hamilton (Clean Air Hamilton, 2010). Simply, outdoor air pollutants are collected across the City and then compared to provincial and federal air quality standards (Health Canada, 2006). Data taken form these monitors is used for various purposes, e.g., assessing air quality, informing the public, identifying emission sources, evaluating long-term trends, providing the basis for air policy/program development, evaluating the potential health impacts of air emissions, providing smog advisories, and determining the contribution from U.S. and Canadian sources on Ontario's air quality (MOE, 2011b).

In Hamilton, there are two types of traditional air monitoring networks. The first type is Ontario's Air Quality Index (AQI) monitoring stations situated in West Hamilton, on the Mountain and Downtown (see Appendix 1) (MOE, 2011b). The second type is the Hamilton Air Monitoring Network (HAMN) stations clustered near the industrial core of the City and are part of an industry-funded network (Figure 7). Since 2003, this network aims to assess the point source of emissions (Clean Air Hamilton, 2010). Currently, there are 17 local participating companies in the HAMN (McCarry, 2011), which are committed to operating, maintaining and monitoring air quality on a regular basis as part of the MOE's Source Emissions Monitoring program (SEM) (Clean Air Hamilton, 2010).

Figure 7: Locations of the Hamilton Air Monitoring Network (Clean Air Hamilton, 2010).

7. Mobile Air Monitoring

Since fixed air monitors are usually few in number and placed away from key roads and emission sources, their coverage is limited and inadequate. As well, they do not capture the spatial contrasts in industrial/residential environments (Pouliou et al, 2008; Wallace et al, 2009). As a result, city-wide mobile surveys were launched to identify the transient levels of air pollutants and to draw a clearer picture of the air quality in Hamilton since 2004 (Clean Air Hamilton, 2008). Several mobile air monitoring studies have found that the pollution levels identified by fixed monitors may not reflect the correct pollutant values of the surrounding areas (Vardoulakis et al, 2005; Milton and Steed, 2007; Wallace et al, 2009).

During these studies, levels of SO_2, NO_x, CO and PM are measured at the street level in different places as traverses, industrial areas, traffic intersections and schools. (Corr, 2006, 2008). Additionally, weather conditions and health impacts of air pollutants are studied, and the spatial variability of air pollution and population exposure are analyzed and mapped (Corr, 2006, 2008; Pouliou et al, 2008; Wallace and Kanaroglou, 2008; Wallace et al, 2009, 2010a).

Mobile air monitoring is implemented by driving a van supplied with air monitoring equipment (see Appendix 3) (Corr, 2006, 2008). The collection of data is done on board the vehicle to measure the levels of pollutants simultaneously. A Global Positioning System (GPS) and Geographic Information System (GIS) are also utilized to map air pollutant data locations (Corr, 2006, 2008).

Overall, mobile surveys conducted in Hamilton have revealed that high levels of pollutants are caused by the automobiles, light trucks and heavy trucks (Corr, 2006, 2008; Wallace et al, 2009). More specifically, the highest concentrations of pollutants are near the intersections of major roads and along heavily used roads, especially roads affected by dirt track-out from industrial sites; and it was suggested that these concentrations have formed the so-called "high pollution triangle" joined together by the highway network (Figure 8) (Wallace et al, 2009).

Mobile studies have indicated that industrial sources are significant contributors to point source emissions, particularly for SO_2, and these contributions are often influenced by local traffic emissions (Sahsuvaroglu et al, 2006), and higher levels of pollution related to traffic would be in the west and east ends of the City and on the mountain accesses (Corr, 2006).

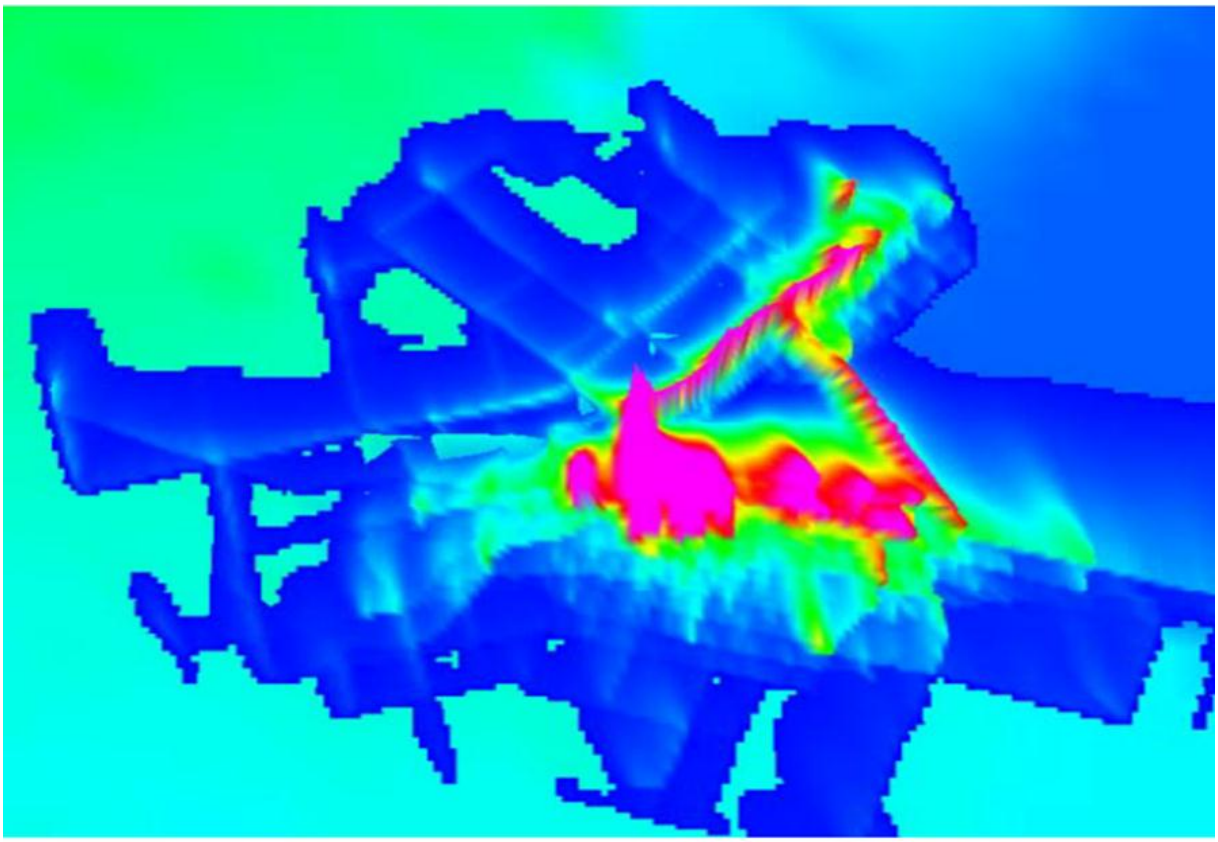


Figure 8: High Pollution Triangle (Corr, 2008).

Wallace and his team have demonstrated that there are very high levels of NO_x (exceeding 600 ppb) near major highways with SO_2 levels (up to 249 ppb) near industrial sources. Both values significantly exceed the hourly maxima recorded by fixed monitors; and the close proximity to roads, with a range of 300 m, is the zone of the greatest health impact (Wallace and Kanaroglou, 2008; Wallace et al, 2009). Further, mobile surveys have also found some roads in the industrial area have re-suspended road dust that leaded to very high levels of PM_{10} (up to 2000 µg/m^3), $PM_{2.5}$ (up to 300 µg/m^3) and PM_1* (up to 125 µg/m^3) (Clean Air Hamilton, 2011).

* PM_1 is airborne particles with 0.1 µm in diameter.

8. Dispersion of Air Pollutants

The levels of air contaminants are significantly impacted by a number of factors, particularly atmospheric conditions and topographical properties (Romieu, 1998). Due to the distinctive geographical feature and prevailing meteorological conditions of Hamilton, air pollution levels are rather different in each of the upper and lower areas. Consequently, air pollutants are usually higher beneath the escarpment where there is more industrial production and denser urban growth (see Appendices 4, 5, 6 and 7) (Wallace et al, 2009). Additionally, the levels of pollutants can rise considerably for a short time, most especially in the spring and fall when certain unusual weather conditions result in atmospheric inversions, which may last from 2 to 12 hours (Clean Air Hamilton, 2011). It is known that greater areas and greater numbers of people are exposed to higher air pollution concentrations under inversion conditions in which air masses close to the earth surface are unable to move upwards, resulting in trapping more air pollutants and making the situation worse than in normal conditions (Wallace et al, 2009).

Mobile surveys conducted between 2005 and 2007 have shown the relationships between industrial emissions, traffic emissions and predicted health impacts of some pollutants under different atmospheric conditions (Corr, 2008; Wallace and Kanaroglou, 2009). As shown in Figures 9 and 10, both heavy industrial activities and highway traffic clearly affect the percentage of aggregated health impacts (AHI) under prevailing southwest (SW) winds, northeast (NE) winds and thermal inversion conditions, respectively. As seen in Figure 10, mobile surveys have demonstrated that emissions of both traffic and industry have significant health influences on much greater numbers of residents and over wider areas when there are winds and atmospheric inversions (Corr, 2008; Clean Air Hamilton, 2009).

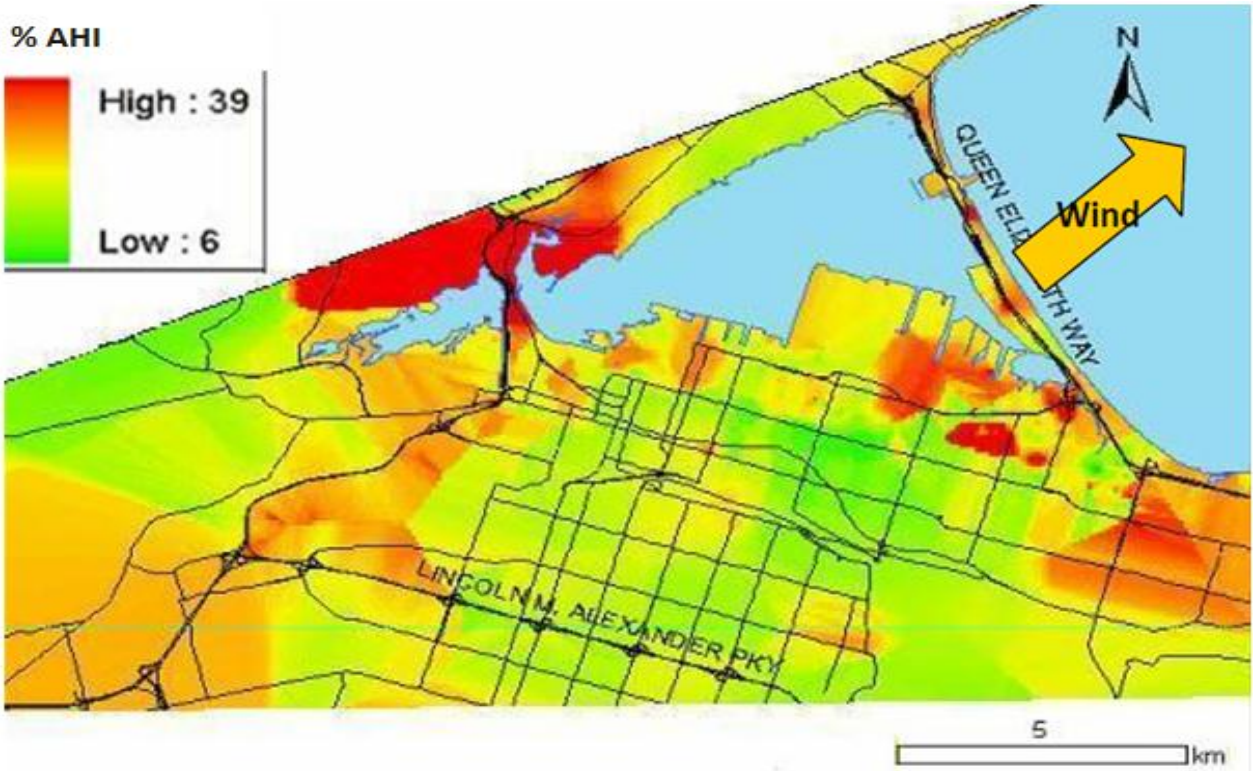


Figure 9: Average Health Impacts under prevailing SW wind in Hamilton (Clean Air Hamilton, 2009).

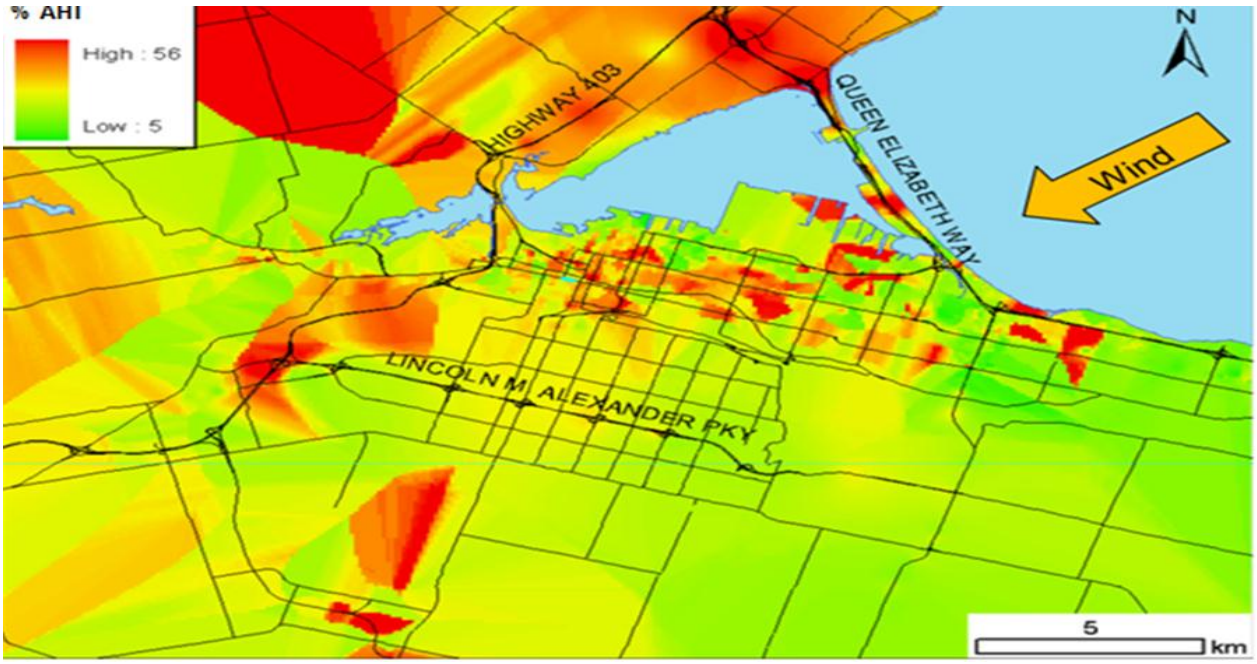


Figure 10: Average Health Impacts under NE wind and inversion conditions in Hamilton (Corr, 2008).

9. Air Quality Index (AQI)

The MOE reports and publishes round the clock numeric data measured at fixed monitoring stations. This information represents the real-time levels of air pollutants, so that the public can know when pollutants are present and in what concentrations. This information is relayed via the Air Quality Index (AQI) with forecasts for two days. Currently, the MOE's AQI depends on Canadian air quality criteria for six pollutants: $PM_{2.5}$, NO_2, SO_2, CO, total reduced sulphur compounds (TRS), and GLO (MOE, 2011a).

Ontario's AQI is an increasing continuum scale divided into five categories. Each category is assigned a descriptor and a color code (Figure 11), which may be explained in terms of health impacts (see Appendix 3). However, the calculation of AQI value is based only on one of the six pollutants, which has the highest value on its scale. As a consequence, the AQI value will usually be determined by ozone during the summer months when the concentration of ozone tend to be high in the air, whereas the AQI value will be affected by levels of $PM_{2.5}$ in the spring and autumn (MOE, 2011a).

Air Quality Index (AQI) Categories	
AQI Ranges and Categories	Colour
0-15 Very Good	
16-31 Good	
32-49 Moderate	
50-99 Poor	
100+ Very Poor	

Figure 11: Air Quality Index Categories (Clean Air Hamilton, 2008).

Based on the annual readings of Ontario's AQI recorded in 2009 throughout Hamilton, it seems that most air quality indices ranged between good and very good categories (Table 3) (MOE, 2011b).

In addition to publishing AQI data, the MOE also issues smog advisories when the AQI becomes greater than 49 for at least one hour on a given day or when AQI is expected to exceed a value of 49 on an upcoming day. Smog advisories are issued to alert the public when elevated levels of air pollution exist, most specifically due to the levels of GLO and/or PM in a local context. In 2010, eight smog advisories were declared, and only two of them were considered as poor air quality days (Clean Air Hamilton, 2011).

Table3: The Percentage Distribution of Hourly AQI Readings for Hamilton 2009 (MOE, 2011b).

Location	Valid Hours	Percentage of Valid Hours AQI in Range					No. of Days at Least 1h>49
		Very Good 0-15	Good 16-31	Moderate 32-49	Poor 50-99	Very Poor 100+	
Hamilton West	8683	48.2	48.9	3.0	0	0	0
Hamilton Downtown	8745	41.0	54.4	4.6	<0.1	0	1
Hamilton Mountain	8754	34.5	59.6	5.9	0.1	0	2

10. Air Quality Health Index (AQHI)

Given that the AQI is based on the single and highest pollutant only, its values cannot reflect the additive effects of other pollutants. Thus, a new air quality index was required in order to provide information on the cumulative health effects of surrounding air. The AQHI is a federal and health-driven metric jointly developed by Health Canada and Environment Canada, in cooperation with different organizations and stakeholders. This metric provides people with

valuable information about the current status of air quality. Also, it provides them with health advices so that they can minimize their exposures to the negative effects of air pollution. Consequently, individuals will be given preferences for proper responses, maximizing their well-being (Environment Canada, 2011).

Since 2008, the AQHI was piloted in the British Columbia Interior and Nova Scotia and is currently implemented in 49 locations across Canada, including Hamilton as of June 2011. The use of this scale is sprawling and replacing the AQI as the public tool of air quality information (Clean Air Hamilton, 2011).

AQHI is calculated hourly depending on the relative risks of a combination of three common air pollutants, GLO, $PM_{2.5,\ 10}$ and NO_2, which pose the best indicators of the effects of air pollution on human health. SO_2 and CO are not taken into account as they are not correlated with additional health impacts according to the Government of Canada. As well, this tool gives a forecast of maximums of local air quality for the next day. The results of calculations are then converted to a number on an easily readable 10-point scale in order to refer to the level of health risk related to local air quality (Environment Canada, 2011). Each range is assigned a descriptor and a color code (Figure 12), and each range is associated with standardized public health advice (Table 4) (Environment Canada, 2008).

Figure 12: Air Quality Health Index Ranges (Environment Canada, 2011).

Health Risk	Air Quality Health Index	Health Messages	
		At Risk Population*	General Population
Low Risk	1 - 3	**Enjoy** your usual outdoor activities.	**Ideal** air quality for outdoor activities.
Moderate Risk	4 - 6	**Consider reducing** or rescheduling strenuous activities outdoors if you are experiencing symptoms.	**No need to modify** your usual outdoor activities unless you experience symptoms such as coughing and throat irritation.
High Risk	7 - 10	**Reduce** or reschedule strenuous activities outdoors. Children and the elderly should also take it easy.	**Consider reducing** or rescheduling strenuous activities outdoors if you experience symptoms such as coughing and throat irritation.
Very High Risk	Above 10	**Avoid** strenuous activities outdoors. Children and the elderly should also avoid outdoor physical exertion.	**Reduce** or reschedule strenuous activities outdoors, especially if you experience symptoms such as coughing and throat irritation.

Table 4: Air Quality Health Index and Health Advices (Environment Canada, 2008).

11. Is Hamilton's Air Clean?

According to the 2009 Report issued by the MOE, it seems that the provincial standards for NO_2, CO, SO_2, and $PM_{2.5}$ were not exceeded at any of the fixed air monitoring locations in Hamilton. By contrast, the levels of GLO are still above the Canada-Wide Standards (CWS) (MOE, 2011b).

Additionally, the levels of TRS, such as Benzene and BaP, showed increases in 2010 when compared to the concentrations measured in 2009. This change may be attributed to the industrial activities increased in 2010. Also, although the levels of SO_2 in Hamilton have continued to decrease in recent years, they tend to be higher compared to other southern Ontario cities because of higher emissions from local industrial activities (Clean Air Hamilton, 2011).

However, since the mid-1990s, Hamilton's local air quality observed at the downtown monitor has experienced significant proportional reductions in the levels of TRS (99%), Benzene

(69%), BaP (55%), SO_2 (50%), NO_2 (41%), TSP (34%), $PM_{2.5}$ (34%) and PM_{10} (9%) (Clean Air Hamilton, 2011). Building on that, it seems that there have been large decreases and constant improvements in the levels of all air pollutants except for GLO. Also, the ambient levels of TRS, SO_2 and NO_x have decreased steadily, whereas the levels of TSP (i.e. $PM_{2.5}$, PM_{10}) have decreased modestly (Clean Air Hamilton, 2011).

12. Improving Hamilton's Air Quality

Hamilton's air quality has improved significantly over the years due to improvements attributable to various concerted measures such as effective regulations, community initiatives, sustainable technologies etc. In order to address the local air quality concerns and to meet federal pollution reduction criteria, the Regional Municipality of Hamilton-Wentworth (RMHW), the MOE and Environment Canada have established in 1997 the Hamilton Air Quality Initiative (HAQI), which is now known as Clean Air Hamilton (CAH). Since then, CAH has achieved necessary steps as initiating air quality research, providing decision-makers with policy advice and information, encouraging local companies to reduce air emissions, and supporting behavioural changes amongst individuals (HAQI, 1997).

CAH has a continuing strategic plan coupled to air quality and climate change. This plan consists of nine substantial issues: Public Health Protection, Active and Sustainable Transportation, Smart Drivers, Air Quality Communications, Climate Change, Emission Reduction Strategies, Energy Conservation, Land Use Planning, and Tree Programs. CAH plans to focus attention on them over the next 2-3 years (Clean Air Hamilton, 2011).

Moreover, the City of Hamilton in 2008 approved the Air Quality and Climate Change Strategic Plan by which the City persists in meeting emission targets of 10% reduction of 2005

greenhouse gases levels by 2012, followed by 20% reduction of 2005 greenhouse gases levels by 2020 (Clean Air Hamilton, 2011).

As a matter of fact, the city of Hamilton has a number of long range decision-making processes and developing strategies that will help reduce emissions and adapt to climate change, such as Hamilton's 30-year Growth Related Integrated Development Strategy (GRIDS), The New Official Plan and the Transportation Master Plan. Besides, the City is implementing the policies of the Ontario Provincial Policy Statement (PPS) into its long-term strategic plans, which will direct the city towards its Vision 2020 sustainable community goals (Clean Air Hamilton, 2011).

At the provincial level, a number of air quality actions was taken to meet the federal emission standards For instance, the MOE has a reporting system known as Local Poor Air Quality Notification that is issued on days when Hamilton's air quality is poor because of increased PM levels accompanied by inversion and wind conditions. By this system, about 30 local companies would be notified to voluntarily reduce their emissions and control their dust-generating activities. Each company has its own plan that could contain delaying materials-handling, boosting property and road sweeping, reducing some production processes and so on (Clean Air Hamilton, 2010).

In addition, the Government of Ontario has set regulations and procedures to enhance the federal vehicle emission standards and technologies, including the curtailment of sulphur content in transportation fuels. For instance, emissions trading regulations (Ontario Reg. 397/01 and Ontario Reg. 194/04), emissions controls at Ontario smelters, phase-out of coal-fired producing facilities, and Drive Clean emissions testing have achieved partial reductions in the emissions of NO_x, CO, SO_2. Also, the Province of Ontario in 2005 enacted Regulation 419/05 as a new

framework for local air quality in order to protect human health and the environment against adverse effects of local industrial emissions, This regulation integrated more sophisticated dispersion modeling to identify the health and environmental outcomes of a given contaminant source. By virtue of this regulation, the MOE is able to set standards based on effects of air pollutants (Clean Air Hamilton, 2010).

At the federal level, the Government of Canada is also working to develop strategies that ensure cleaner air and a cleaner environment for all Canadians. One of the noteworthy accomplishments is the Air Quality Agreement signed in 1991 with the United States, which contributed to reduce transboundary smog and acid rain (Environment Canada, 2010c).

Further, in 2000, Environment Canada has launched the Clean Air Agenda in response to primary government priorities and Canadian concerns about air quality. This agenda concentrates on five primary areas: reducing transboundary air pollution, decreasing transportation emissions, curtailing industrial emissions, promoting the science, and engaging the public (Environment Canada, 2006). As well, the federal government requires many manufacturing sources of pollution to set up pollution prevention (P2) plans which sketch out methods to alter production processes, redesign products, introduce alternative materials, improve management and training, install new and cleaner technologies, and increase energy conservation (Clean Air Hamilton, 2011).

Based on the progress of the Air Quality Agreement, the Government of Canada in 2003 has signed with the United States the Border Air Quality Strategy. This strategy has increased the collaboration to reduce cross-border air pollution by launching three key pilot projects that attain greater opportunities for harmonized air quality management between both countries (Environment Canada, 2010d). Recently, the Canadian Council of Ministers of the Environment

(CCME) has endorsed the Comprehensive Air Management System (CAMS) in 2010. The ultimate objective of CAMS is to improve air quality management across Canada, including developing new legislative and policy frameworks to address airshed and air zone management (Canadian Council of Ministers of the Environment, 2010).

13. Conclusions

The city of Hamilton has its own concerns, resources, and outlook regarding long-range policies to address the complex environmental problems, including air pollution. Hamilton's actions on clean air, along with successful cooperation among community members and all levels of government are playing an important role in reducing air pollution. The appropriate implementations of policies in tandem with the use of sustainable technologies are considerably assisting in curtailing air pollutants. It is obvious that all measures taken to reduce emissions of harmful air pollutants have a common challenge, in other words, finding the balance between the needs of Canadians for transport, energy, and goods and the goals of environmental protection.

Apparently, Hamilton's ambient air has a decreasing trend in the levels of most air pollutants since the mid-1990s. However, mobile air monitoring studies achieved in Hamilton have revealed that emissions from mobile sources, residential and industrial operations, road dusts, and fugitive dusts are the primary local sources of contaminants in the City. These studies have also found that there are higher levels of air pollutants along major highways and at major intersections due to vehicular emissions; and that residential districts have much lower levels of contaminants from mobile sources. Anyway, the City through its long-term strategic plans aims

to clean up local air quality, diminish greenhouse gas emissions, and maximize energy conservation till attaining the objectives of Hamilton's Vision 2020 sustainable community.

14. Recommendations

In the light of the current study, a number of recommendations arise as:

1. The network of fixed air monitoring stations should be expanded to cover more areas, including other point sources.
2. The surveys of mobile air monitoring should be extended for longer periods in order to monitor additional point sources, particularly non-operational industries in the winter months.
3. More spatiotemporal research is wanted to better appraise the long-term and relative health effects of different air pollutants, in particular transportation-based pollutants near major traffic.
4. Community's individuals should take advantage from communication tools of air quality by using the AQHI, especially those having respiratory or cardiac difficulties.
5. Cyclists, joggers and pedestrians should be separated from main roadways by separating walking and cycling routes from heavily used ways and by encouraging residents to practice sports in places far enough from such roads.
6. People should be encouraged to curtail transportation-based emissions by using transportation alternatives as public transit, bicycles, hybrid vehicles, etc.
7. Reduction of re-suspended road dust should be taken into account by encouraging industrial sectors and stakeholders to develop best practices to reduce fugitive dust emissions and track-out, such as roads paving and cleaning etc.

Appendices

Appendix 1: Locations of Provincial Air Quality Network in Hamilton (MOE, 2011b).

ID	Area	Station Location	Year	Latitude (D:M:S)	Longitude (D:M:S)	Air Intake (AGL)	Type	AQI	O_3	$PM_{2.5}$	NO_2	CO	SO_2	TRS
29000	Downtown	Elgin St./ Kelly St.	1987	43°15`28.0``	-79°51`42.0``	4	A C N	U	T	T	T	T	T	T
29114	Mountain	Vickers Rd./ E. 18th St.	1985	43°13`45.9``	-79°51`46.0``	3	A C N	U	T	T	T		T	
29118	West	Main St.W./ HWY 403	1985	43°15`26.8``	-79°54`27.9``	3	A	U	T	T				

ID, station identfication number; Year: year station began monitoring; Air intake, height of air intake above ground (m); A, ambient; C, The Canada-Wide Standards (CWS); N, The National Air Pollution Surveillance (NAPS); U, Urban; T, Telemetry.

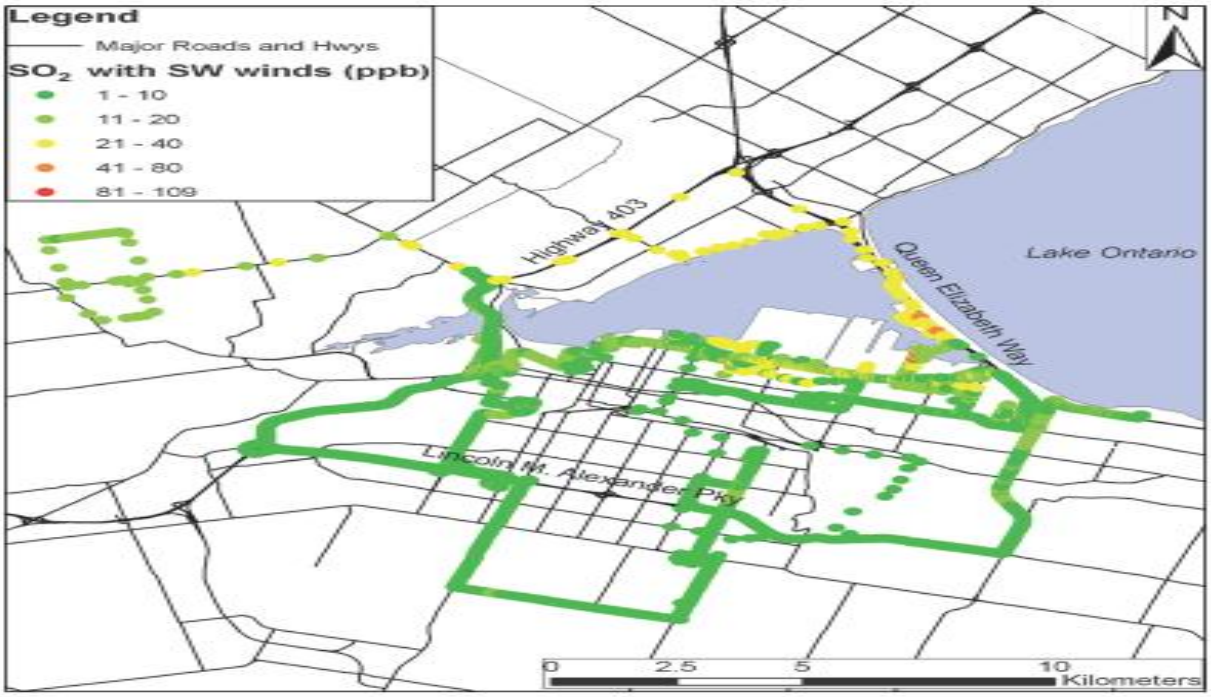
Appendix 2: Mobil Monitoring Unit (Corr, 2008).

Appendix 3: Ontario's Air Quality Index Pollutants and Their Health Impacts (MOE, 2005).

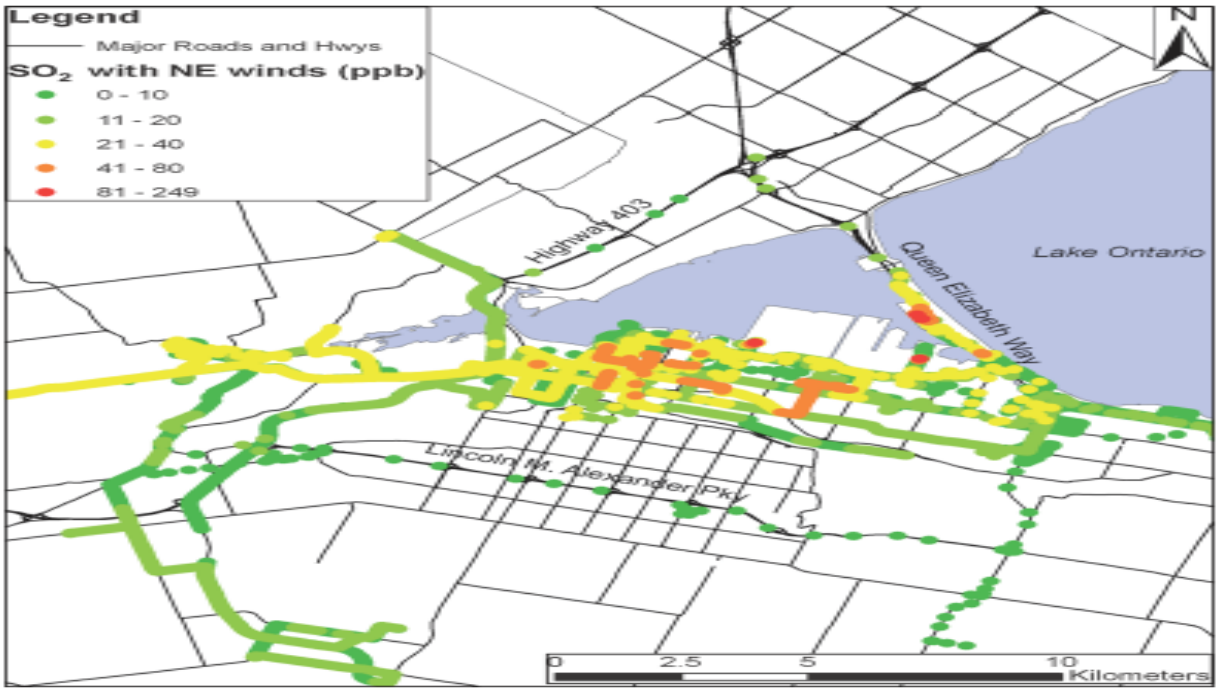
Index	Ozone (O_3)	Fine Particulate Matter ($PM_{2.5}$)	Carbon Monoxide (CO)	Nitrogen Dioxide (NO_2)	Sulphur Dioxide (SO_2)	Total Reduced Sulphur (TRS) Compounds
0-15	No health effects are expected in healthy people	Sensitive populations may want to exercise caution	No health effects are expected in healthy people	No health effects are expected in healthy people	No health effects are expected in healthy people	No health effects are expected in healthy people
16-31	No health effects are expected in healthy people	Sensitive populations may want to exercise caution	No health effects are expected in healthy people	Slight odour	Damages some vegetation in combination with ozone	Slight odour
32-49	Respiratory irritation in sensitive people during vigorous exercise; people with heart/lung disorders at some risk; damage to very sensitive plants	People with respiratory disease at some risk	Blood chemistry changes, but no noticeable impairment	Odour	Damages some vegetation	Odour
50-99	Sensitive people may experience irritation when breathing and possible lung damage when physically active; people with heart/lung disorders at greater risk; damage to some plants.	People with respiratory disease should limit prolonged exertion; general population at some risk	Increased symptoms in smokers with heart disease	Air smells and looks brown; some increase in bronchial reactivity in asthmatics	Odour; increasing vegetation damage	Strong odour
100 and over	Serious respiratory effects even during light physical activity; people with heart/lung disorders at high risk; more vegetation damage	Serious respiratory effects even during light physical activity; people with heart disease, the elderly and children at high risk; increased risk for general population	Increasing symptoms in non-smokers with heart disease; blurred vision; some clumsiness	Increasing sensitivity for asthmatics and people with bronchitis	Increasing sensitivity for asthmatics and people with bronchitis	Severe odour; some people may experience nausea and headaches

* Please note that the information in this table will be reviewed and may change.

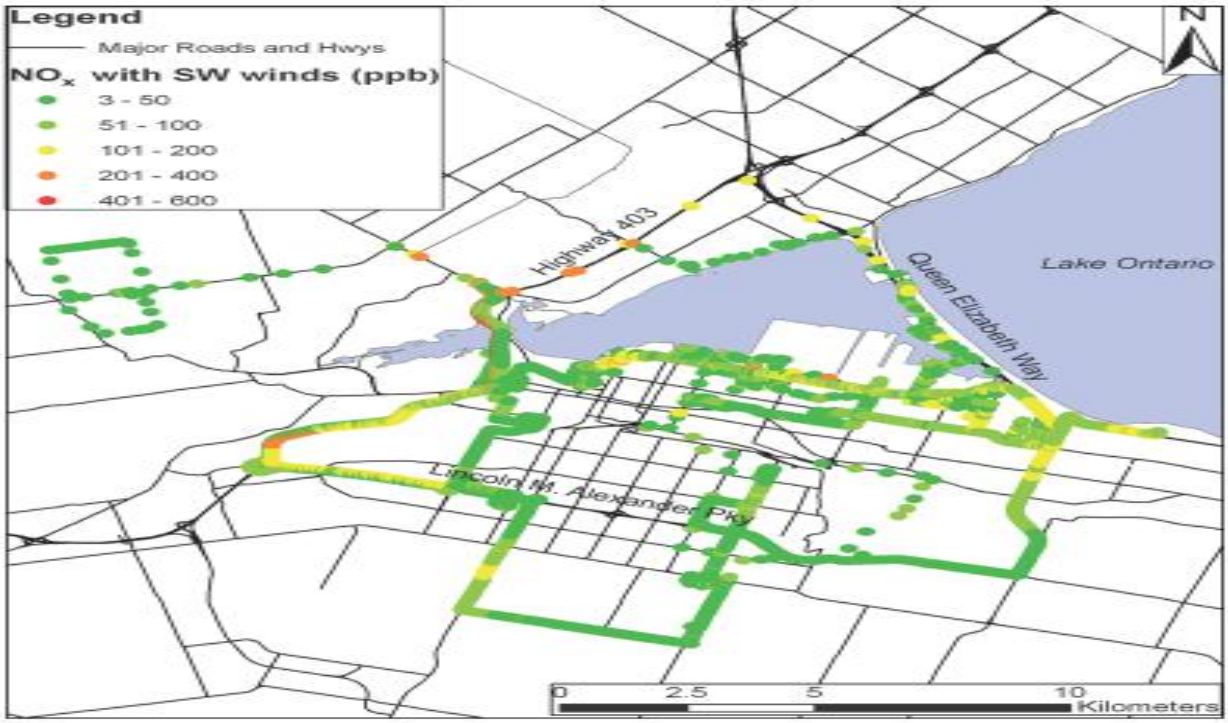
Appendix 4: SO_2 levels on traverses under prevailing SW wind conditions in Hamilton (Wallace et al, 2009).



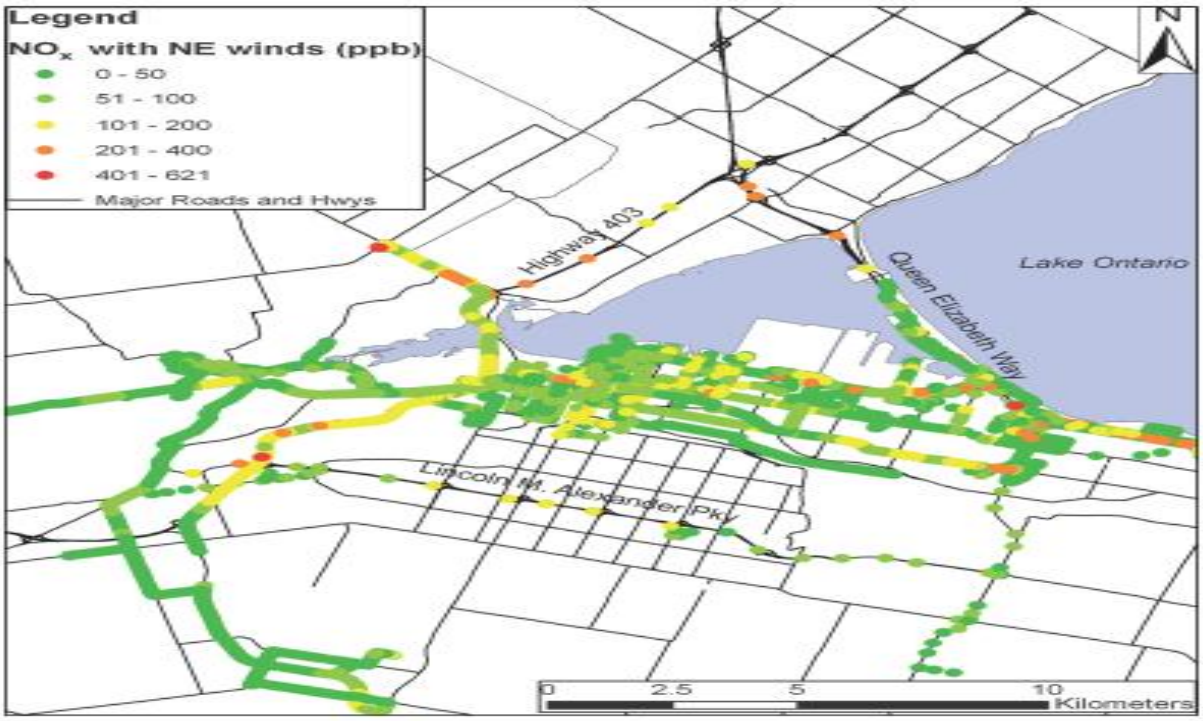
Appendix 5: SO_2 levels on traverses under NE wind conditions in Hamilton (Wallace et al, 2009).



Appendix 6: NO_x levels on traverses under prevailing SW wind conditions in Hamilton (Wallace et al, 2009).



Appendix 7: NO_x levels on traverses under NE wind conditions in Hamilton (Wallace et al, 2009).



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