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Estimating Health Impacts of Urban Air Pollution

Sarath Guttikunda

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(UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution. There is a need to scale-up research applications to the secondary and the tertiary cities which are following in the footsteps of the expanding mega-cities. Advances in information technology, open-data resources, and networking, offers a tremendous opportunity to establish such tools, to help city managers, regulators, academia, and citizen groups to develop a coordinated approach for integrated air quality management for a city.

UEinfo has four objectives: (1) sharing knowledge on air pollution (2) science-based air quality analysis (3) advocacy and awareness raising on air quality management and (4) building partnerships among local, national, and international airheads.

This report was conceptualized, drafted, and designed by the members of UEinfo.

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Estimating Health Impacts of Urban Air Pollution

There are various consequences of being exposed to air pollution due to various pollutants, such as:

- Effects on human health
  - Premature mortality, asthma attacks, respiratory symptoms, chronic bronchitis, oxygen deficiency in blood, eye irritation, and genetic and reproductive damages
- Effects on vegetation
  - Productivity loss and slower photosynthesis for vegetation
- Effects on material and structure
  - Corrosion of metal, accelerated erosion on building and monument
- Effects on comfort and aesthetics
  - Bad smell, reduced vision distance, quick paling of paint on buildings
- Effects on ecosystem (atmosphere, soil and water body)
  - Local (human health), regional (acid rain), and global (climate change)

This paper will focus on the health impact assessment of air pollution.

Health Impacts of Air Pollution

Epidemiological studies in industrial and developing countries have shown that elevated ambient PM levels lead to an increased risk of mortality and morbidity. Health effects range from minor irritation of eyes and the upper respiratory system to chronic respiratory disease, heart disease, lung cancer, and death. Air pollution has been shown to cause acute respiratory infections in children and chronic bronchitis in adults. It has also been shown to worsen the condition of people with preexisting heart or lung disease. Among asthmatics, air pollution has been shown to aggravate the frequency and severity of attacks. Both short-term and long-term exposures have also been linked with premature mortality and reduced life expectancy. The Health Effects Institute (USA) conducted a detailed literature survey on the impact of outdoor air pollution on human health[1].

The health impacts of air pollution depend on the pollutant type, its concentration in the air, length of exposure, other pollutants in the air, and individual susceptibility. The undernourished, very young and very old, and people with preexisting respiratory disease and other ill health, may be more affected by the same concentrations than healthy people. Additionally, developing country poor tend to live and work in the most heavily polluted areas. They are more likely to cook with dirtier fuels resulting in higher levels of indoor and outdoor air pollution. As a result, their elevated risk due to health factors is exacerbated by their increased exposure to PM.

[1] Health Effects Institute @ www.healtheffects.org

According to the World Health Organization (WHO) and other organizations, there is no clear evidence for a threshold below which PM pollution does not induce some adverse health effects, especially for the more susceptible populations – children and the elderly. This situation has prompted a vigorous debate about whether current air quality standards are sufficient to protect public health and reduce damage costs[2].

Studies in India, for instance, have shown that acute respiratory infection (ARI) in children under 5 is the largest single disease category in the country, accounting for about 13 percent of the national burden of disease[3], and children living in households using solid fuels have 2-3 times more risk of ARI than unexposed children (Smith, 1999). In 1995, air pollution in China from fuel combustion was estimated to have caused 218,000 premature deaths (equivalent to 2.9 million life-years lost), 2 million new cases of chronic bronchitis, 1.9 billion additional restricted activity days, and nearly 6 billion additional cases of respiratory symptoms (Lvovsky, 2001). The culprit pollutant in both China and India is believed to be fine PM. While estimates of health impacts are effective in raising overall concern about air quality, they do not specifically answer the question of the sources of fine PM, nor what measures should be taken to reduce the impacts associated with exposure.

Estimating the Health Impacts due to Outdoor Air Pollution

Fundamental equation to estimating the health impacts is as follows

$$\delta E = \beta * \delta C * \delta P$$

Where,

δE = number of estimated health effects (various end points for mortality and morbidity).

β = the dose response function (DRF) for particular health endpoint; this is defined the change in number cases per unit change in concentrations. This is established based on epidemiological studies conducted over a period of time, analyzing the trends in hospital records and air pollution monitoring. More on the DRF's in the following section.

δC = the change in concentrations; this could be change in concentrations between two scenarios being simulated or the concentrations measured above a certain threshold value. Although, WHO claims that there is no threshold over which the health impacts are measured. In general, the impacts are felt at the minute fluctuations of the pollution.

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2 WHO challenges world to improve air quality – www.who.int/mediacentre/news/releases/2006/pr52/en

3 Comparative Quantification of Health Risks - http://www.who.int/publications/cra/en/

$\delta P =$ the population exposed to the incremental concentrations above; this could be on a grid by grid basis or for the city or region on a whole, depending on the level of information available and goal of the analysis.

Dose Response Functions:

Epidemiological studies in industrial and developing countries have shown that elevated ambient PM levels lead to an increased risk of mortality and morbidity. Health effects range from minor irritation of eyes and the upper respiratory system to chronic respiratory disease, heart disease, lung cancer, and death. Air pollution has been shown to cause acute respiratory infections in children and chronic bronchitis in adults. It has also been shown to worsen the condition of people with preexisting heart or lung disease. Among asthmatics, air pollution has been shown to aggravate the frequency and severity of attacks. Both short-term and long-term exposures have also been linked with premature mortality and reduced life expectancy. The Health Effects Institute (USA) conducted a detailed literature survey on the impact of outdoor air pollution on human health[4] and the publication "Health Effects of Outdoor Air Pollution in Developing Countries of Asia: A Literature Review (2004)" includes an extensive list of references for follow-up on the dose response functions for various end points and methodologies to conduct epidemiological studies to develop these dose response functions.

For Mortality:

Main Conclusion of HEI's latest study under the PAPA program[5] is that the dose response functions for PM_{10} and $PM_{2.5}$ are the same throughout the world.

For HEI's press release of PAPA program results (see **Figure 1**)

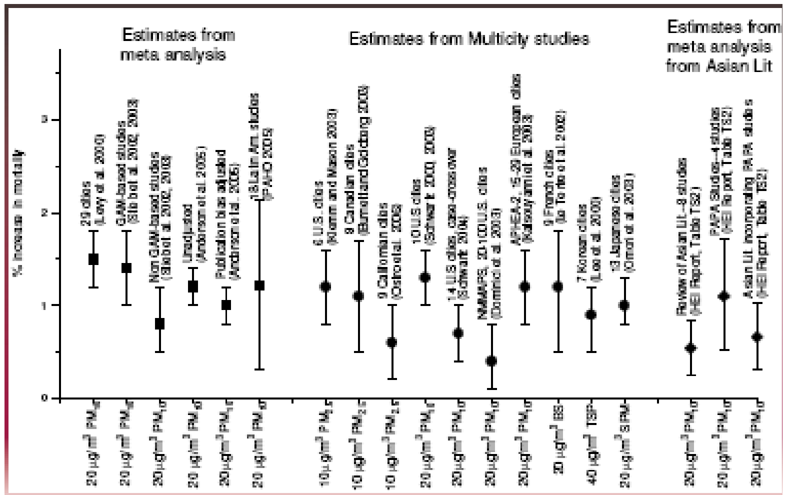
The study's finding of a 0.6% increase in mortality for every 20μg/m³ of exposure to particulate air pollution is strikingly similar to comparable western results (which range from 0.4% to 0.6%) and provide increased confidence in the new Asian results.

A key finding of the study is that the effect of air pollution on daily mortality remained consistent even as the degree of pollution increased to high levels, proceeding in a largely linear pattern to levels over 100 μg/m³ (a level five times the current WHO PM_{10} guideline of 20 μg/m³).

In other words, there is NO real need to conduct epidemiological studies every time we need to assess the dose response functions in a city. These studies are time consuming and constrained by budgets. Of course, if a program has enough time and resources, the city should conduct their own epidemiological studies to investigate

4 "Health Effects of Outdoor Air Pollution in Developing Countries of Asia: A Literature Review" - http://pubs.healtheffects.org/view.php?id=3
5 PAPA – Public Health and Air Pollution in Asia - http://www.cleanairnet.org/caiasia/1412/article-48844.html

these functions and utilize the necessary data for impact assessment and decision making.



For legible snapshot, please refer to the presentation Dr. Sumi Mehta @ http://www.BAQ2008.org

Figure 1: Effects of PM10 on mortality: Asia in Global context[6]

Dose Response Function for Mortality =
0.6% increase in the incidence rates for 20 μg/m^3 increase in the concentrations of PM_{10} (HEI)
(A conservative estimate = 0.15%)

Also see latest report by California Air Resources Board[7]
@ http://www.arb.ca.gov/research/health/pm-mort/pm-mort.htm

The incidence rates for mortality from WHO are presented in Table 1

Accordingly, example average dose response functions for regions are as follows

Global	= 0.6% /20 *223/1000 = 0.000067 cases per μg/m^3 exposure per capita
Africa	= 0.6% /20 *403/1000 = 0.000121 cases per μg/m^3 exposure per capita
East Asia	= 0.6% /20 *185/1000 = 0.000056 cases per μg/m^3 exposure per capita
Americas	= 0.6% /20 *166/1000 = 0.000050 cases per μg/m^3 exposure per capita
South Asia	= 0.6% /20 *215/1000 = 0.000065 cases per μg/m^3 exposure per capita
Middle East	= 0.6% /20 *197/1000 = 0.000059 cases per μg/m^3 exposure per capita
Europe	= 0.6% /20 *134/1000 = 0.000040 cases per μg/m^3 exposure per capita

These are average functions (authors interpretation); Use with discretion

[6] Source: From presentation by Dr. Sumi Mehta, Health Effects Institute, "Emerging Evidence on the Health Effects of Air Pollution in Asia" @ http://baq2008.org/spa-mehta

[7] California Air Resources Board (2008) "Methodology for Estimating Premature Deaths Associated with Long-term Exposure to Fine Airborne Particulate Matter in California" @ http://www.arb.ca.gov/research/health/pm-mort/pm-mort.htm

Table 1: Mortality Incidence Rates by WHO[8] for Year 2006
Probability of dying between 15 to 60 years per 1000 people

In Africa

Country	Rate	Country	Rate
Algeria	135	Liberia	457
Angola	493	Madagascar	268
Benin	327	Malawi	533
Botswana	468	Mali	427
Burkina Faso	427	Mauritania	288
Burundi	434	Mauritius	161
Cameroon	436	Mozambique	477
Cape Verde	230	Namibia	336
Central African Republic	467	Niger	478
Chad	445	Nigeria	423
Comoros	214	Rwanda	385
Congo	386	Sao Tome and Principe	241
Côte d'Ivoire	431	Senegal	271
Demo. Rep. of the Congo	417	Seychelles	174
Equatorial Guinea	449	Sierra Leone	508
Eritrea	251	South Africa	564
Ethiopia	326	Swaziland	662
Gabon	350	Togo	336
Gambia	278	Uganda	495
Ghana	331	United Rep. of Tanzania	504
Guinea	343	Zambia	617
Guinea-Bissau	407	Zimbabwe	751
Kenya	416		
Lesotho	722		

Average for Mortality incidence rate for Africa = 403

In South Asia

Country	Rate	Country	Rate
Bangladesh	254	Myanmar	276
Bhutan	218	Nepal	286
South Korea	200	Sri Lanka	166
India	241	Thailand	210
Indonesia	212	Timor-Leste	199
Maldives	103		

Average for Mortality incidence rate for South Asia = 215

[8] WHO Core Health Indicators - http://www.who.int/whosis/database/core/core_select.cfm

In East Asia & Pacific

Country	Rate	Country	Rate
Australia	65	New Zealand	75
Brunei Darussalam	88	Niue	164
Cambodia	257	Palau	227
China	116	Papua New Guinea	273
Cook Islands	123	Philippines	219
Fiji	212	Republic of Korea	84
Japan	67	Samoa	220
Kiribati	247	Singapore	67
Laos	308	Solomon Islands	164
Malaysia	155	Tonga	165
Marshall Islands	290	Tuvalu	262
Micronesia	179	Vanuatu	187
Mongolia	255	Viet Nam	155
Nauru	381		

Average for Mortality incidence rate for East Asia & Pacific = 185

In Americas

Country	Rate	Country	Rate
Antigua and Barbuda	151	Guyana	246
Argentina	124	Haiti	282
Bahamas	195	Honduras	181
Barbados	118	Jamaica	177
Belize	255	Mexico	122
Bolivia	208	Nicaragua	181
Brazil	176	Panama	108
Canada	72	Paraguay	132
Chile	91	Peru	136
Colombia	131	Saint Kitts and Nevis	165
Costa Rica	95	Saint Lucia	154
Cuba	104	St. Vincent &Grenadines	238
Dominica	150	Suriname	222
Dominican Republic	209	Trinidad and Tobago	199
Ecuador	166	United States of America	109
El Salvador	191	Uruguay	125
Grenada	232	Venezuela	142
Guatemala	222		

Average for Mortality incidence rate for Americas = 166

In Middle East

Country	Rate	Country	Rate
Afghanistan	473	Oman	133
Bahrain	104	Pakistan	206
Djibouti	343	Qatar	67
Egypt	186	Saudi Arabia	178
Iran (Islamic Republic of)	138	Somalia	323
Iraq	436	Sudan	296
Jordan	152	Syrian Arab Republic	153
Kuwait	62	Tunisia	136
Lebanon	162	United Arab Emirates	78
Libyan Arab Jamahiriya	146	Yemen	250
Morocco	119		

Average for Mortality incidence rate for Middle East = 197

In Europe

Country	Rate	Country	Rate
Albania	137	Latvia	223
Andorra	74	Lithuania	223
Armenia	184	Luxembourg	83
Austria	79	Malta	62
Azerbaijan	188	Monaco	86
Belarus	251	Netherlands	70
Belgium	86	Norway	70
Bosnia and Herzegovina	111	Poland	145
Bulgaria	157	Portugal	93
Croatia	113	Republic of Moldova	237
Cyprus	58	Romania	157
Czech Republic	108	Russian Federation	300
Denmark	88	San Marino	48
Estonia	186	Serbia	141
Finland	96	Slovakia	136
France	91	Slovenia	104
Georgia	173	Spain	75
Germany	81	Sweden	64
Greece	76	Switzerland	63
Hungary	177	Tajikistan	200
Iceland	59	Republic of Macedonia	121
Ireland	72	Turkey	123
Israel	68	Turkmenistan	291
Italy	64	Ukraine	264
Kazakhstan	315	United Kingdom	80
Kyrgyzstan	236	Uzbekistan	185

Average for Mortality incidence rate for Europe = 134

For Morbidity:

Based on studies conducted in the past, **Table 2**, presents an average set of dose response functions for morbidity end points.

Table 2: Average dose response functions for morbidity end points

Morbidity Health Endpoint	Dose response function (β) (effects/1μg/m³ change/per capita)
Adult Chronic Bronchitis	0.000040
Child Acute Bronchitis	0.000544
Respiratory Hospital .Admission	0.000012
Cardiac Hospital Admission	0.000005
Emergency Room Visit	0.000235
Asthma Attacks	0.002900
Restricted Activity Days	0.038280
Respiratory Symptom Days	0.183000

Reference:
These are average numbers based a number of studies conducted in Asia and Africa

1. Lvovsky, et al. 2000. "Environmental Costs of Fossil Fuels: A Rapid Assessment Method with Application to Six Cities." Environment Department Paper No. 78, The World Bank, Washington DC, USA
2. Bell, et al., 2006. "The avoidable health effects of air pollution in three Latin American cities: Santiago, São Paulo, and Mexico City." Environmental Research, 100, March 2006, 431-440.
3. Pope, C. A., III and Dockery, D. W. 2006. Health effects of fine particulate air pollution: Lines that connect. Journal of the Air Waste Management Assoc. 56(6):709-742.
4. Ostro, et al., 1998. "Estimating the Health Impact of Air Pollution: Methodology and an Application to Jakarta." Working paper series, The World Bank, Washington DC, USA
5. Li, J., and S. K. Guttikunda, et. al., 2004. "Quantifying the Human Health Benefits of Curbing Air Pollution in Shanghai." Journal of Environmental Management. 70, pp. 49-62
6. URBAIR Air Quality Management Series, The World Bank, Washington DC, USA
7. HEI, 2004. "Health Effects of Outdoor Air Pollution in Developing Countries of Asia: A Literature Review." Health Effects Institute, Boston, USA
8. Ostro, et al., 1994. "Estimating the Health Effects from Air Pollutants: A Method With an Application to Jakarta.' World Bank Policy Research Working Paper #1301
9. Xu, et al., 1994, 'Air Pollution and Daily Mortality in Residential Areas of Beijing, China.' Archives of Environmental Health, 49, pp. 216-222
10. SAES, 2000, 'Shanghai Energy Option and Health Impact.' Report prepared by Shanghai Academy of Environmental Sciences and Shanghai Medical University
11. "Cost of Pollution in China", East and Pacific Region, The World Bank, Washington DC - http://go.worldbank.org/FFCJVBTP40

These are average functions (authors interpretation); Use with discretion

Estimating the Health Impacts - An Example Calculation

Most often, the health impacts are calculated in terms of number of effects avoided, either due to introduction of an intervention (comparing what-if scenarios) or bringing the concentrations below a threshold value (comparing what-now scenarios).

Let us assume that your city is divided into a 4x4 grid cells and the example calculations will be conducted for one endpoint – mortality, using global average dose response function on **Page 6**.

(This exercise can also be performed in a non-grid cell fashion – like prefectures on a GIS map by provinces or wards or districts or blocks. The grid cells are assumed for simplicity)

30	30	30	40
30	95	90	100
65	80	100	120
80	80	70	45

Assumed PM10 levels in the city (μg/m^3)

100	100	100	100
100	200	200	80
150	200	200	80
150	150	100	120

Assumed population levels in the city

For the estimation of health impacts, different types of scenarios possible for evaluation are

1. Number of cases incurred above a threshold value – this threshold value can be a WHO standard or national ambient standard.
2. Number of cases incurred above an average concentration target for the area
3. Comparison of scenarios, either with a business as usual case or between the scenarios

Example 1: Number of effects incurred above a threshold (say 40 μg/m^3)

	55	50	60
25	40	60	80
40	40	30	5

PM10 levels in excess of threshold (μg/m^3)

	200	200	80
150	200	200	80
150	150	100	120

Assumed population at risk

Now, apply the equation on **Page 4** for each cell, using the dose response function (0.000067) on **Page 6**, then add the results from all the cells for extra number of cases incurred due to not exceeding the threshold concentrations in the city. For this example, <u>number of extra cases incurred or avoidable deaths are ~ 4,794</u>.

Example 2: Number of effects incurred above a threshold (say 15 μg/m^3)

The calculations in Example 1 will differ with the assumed threshold value. For the same scenario, under a new threshold value of 15 μg/m^3, the concentrations in excess will look like the below, with more population at the risk of exposure.

15	15	15	25
15	80	75	85
50	65	85	105
65	65	55	30

PM10 levels in excess of threshold (μg/m^3)

100	100	100	100
100	200	200	80
150	200	200	80
150	150	100	120

Assumed population at risk

Now, apply the equation on **Page 4** for each cell, using the dose response function (0.000067) on **Page 6**, then add the results from all the cells for extra number of cases incurred due to exceeding the threshold concentrations in the city. For this example, <u>number of extra cases incurred or avoidable deaths are ~ 8,093</u>.

Example 3: In case of scenario analysis.

Let us assume the dispersion calculations are made for two scenarios – one for business as usual presented on **Page 11** and a new scenario with control measures for some sectors.

30	30	30	40
30	95	90	100
65	80	100	120
80	80	70	45

Assumed PM10 levels for Business as Usual ($\mu g/m^3$)

22	15	15	20
20	60	55	80
65	44	66	80
60	60	50	20

Assumed PM10 levels for a New Scenario ($\mu g/m^3$)

Subtracting the scenario concentrations from the business as usual

8	15	15	20
10	35	35	20
0	36	34	40
20	20	20	25

PM_{10} reductions under New scenario ($\mu g/m^3$)

100	100	100	100
100	200	200	80
150	200	200	80
150	150	100	120

Assumed population at risk

Now, apply the equation on **Page 4** for each cell, using the dose response function (0.000067) on **Page 6**, then add the results from all the cells for extra number of cases incurred due to not exceeding the threshold concentrations in the city. For this example, number of extra cases incurred or avoidable deaths are ~ 3,390.

Example 4: City Average.

If enough data doesn't exist on spatial variation of the concentrations, a first order estimate is to use city level average concentrations.

Note that this is a crude way of estimating health impacts and for better analysis, one should use spatially segregated data to reflect the population distribution and exposure levels due to various pollution levels.

Now, let us assume the city average concentration is 120 $\mu g/m^3$. This could be coming from monitoring data or modeling estimates.

If an pollution control or prevention intervention introduced in the city is expected to reduce the concentrations by 20 $\mu g/m^3$ on an average basis and if the population of the city exposed to these concentrations is say 2 million, then

the number of mortality cases incurred in this example city
= 0.000067 * 20 * 2,000,000
= 2,680

Limitations

1. This is a simplified method to estimate health impacts and the analysts should, at some point, take into consideration the sensitivity of the linkages between air pollution and health impacts.
2. For example, the health impacts differ between age groups and that is NOT discussed in this paper, only averages are considered.
3. This methodology is based on empirical dose response functions based on epidemiological studies conducted around the world and the calculations based on these should be taken into consideration as guidelines for comparison and decision making and should not be taken literally for conclusions.
4. The uncertainty exists in calculations, every step of the way, but this is a good place to start, especially when comparing scenarios and establishing the cost effectiveness of the interventions with human health estimates as a baseline.
5. The results of this methodology are as good as the inputs. The more detailed the analysis on the spatial distribution of the pollution levels for various scenarios and exposure levels based on the population distribution, the better the results.
6. A literature search of similar studies in the region and the methodologies applied will help better the equation.
7. Last but not the least, the analysis presented in <u>this report is ONLY for the health impacts of particulate pollution</u>. Other impacts like ground level ozone on health and agriculture yield, sulfur on agricultural crops due to acid rain, etc., should be taken into consideration for full cost-benefit analysis and a similar methodology can be applied to estimate those impacts.

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