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HUMAN HEALTH RISKS IN MEGACITIES DUE TO AIR POLLUTION

РИСКИ ДЛЯ ЗДОРОВЬЯ ЧЕЛОВЕКА В МЕГАПОЛИСАХ ИЗ-ЗА ЗАГРЯЗНЕНИЯ ВОЗДУХА

АННОТАЦИЯ. Это исследование оценивает риски для здоровья в мегаполисах по смертности и заболеваемости в результате загрязнения воздуха. Новая модель таблицы, риск смертности / заболеваемости из-за загрязнения воздуха (Ri-MAP), используется для оценки избыточного числа случаев смерти и болезней. В статье исследование оценивает риски для здоровья в городах-миллионниках в плане заболеваемости и смертности от загрязнения воздуха. Оценки риска, полученные от Ri-MAP, представляют реалистичную базовую оценку последствиями загрязнения атмосферного воздуха по сравнению с простыми показателями качества воздуха, и могут быть расширены и улучшены параллельно с развитием сетей мониторинга загрязнения воздуха.

ABSTRACT. This study evaluates the health risks in megacities in terms of mortality and morbidity due to air pollution. A new spreadsheet model, Risk of Mortality/Morbidity due to Air Pollution (Ri-MAP), is used to estimate the excess numbers of deaths and illnesses. In the article the study evaluates the health risks in megacities in terms of mortality and morbidity due to air pollution. The risk estimates obtained from Ri-MAP present a realistic baseline evaluation for the consequences of ambient air pollution in comparison to simple air quality indices, and can be expanded and improved in parallel with the development of air pollution monitoring networks.

КЛЮЧЕВЫЕ СЛОВА: критерии загрязнения, смертность, заболеваемость, относительный риск, сердечно-сосудистый риск, респираторный риск, госпитализация.

KEY WORDS: pollution criteria, mortality, morbidity, relative risk, cardiovascular risk, respiratory risk, hospital admission.

Megacities are very large urban sprawls confronted with a multitude of environmental challenges including soaring air pollution emissions. Thus megacities tend to be global risk areas and their inhabitants are vulnerable to air pollution induced adverse health impacts. Such risks need to be estimated to help initiate national and international efforts to improve the sustainability of megacity life worldwide. Several studies have been conducted on air pollution emissions and their implications in megacities. In the article study evaluates the health risks in megacities in terms of mortality and morbidity due to air pollution. A new spreadsheet model, Risk of Mortality/Morbidity due to Air Pollution (Ri-MAP), is used to estimate the excess numbers of deaths and illnesses. By adopting the World Health Organization (WHO) guideline concentrations for the air pollutants SO2, NO2 and total suspended particles (TSP), concentration - response relationships and a population attributable-risk proportion concept are employed. The Ri-MAP model uses the WHO default values of relative risks and baseline incidences related to different air pollutants and various types of mortality and diseases as listed in Table 1.

Table 1
WHO default values of relative risk (per 10 μg m^{-3} increase of daily averages for SO_2, TSP and NO_2) and baseline incidence (per 100,000) corresponding to mortality and morbidity.

Pollutant	Mortality/Mobidity	Relative Risk (RR)	Baseline incidence Per 100,000 (I)[b]
SO_2	Total	1.004 (1.003–1.0048)[c]	1013
	Cardiovascular	1.008 (1.002–1.012)	497
	Respiratory	1.010 (1.006–1.014)	66
	COPD[a] Morbidity (Hospital Admissions)	1.0044 (1–1.011)	101.4
TSP	Total	1.003 (1.002–1.007)	1013
	Cardiovascular	1.002 (1–1.006)	497
	Respiratory	1.008 (1.004–1.018)	66
	COPD[a] Morbidity (Hospital Admissions)	1.0044 (1–1.0094)	101.4
NO_2	Total	1.002 (1–1.004)	497
	Cardiovascular	1.002 (1–1.004)	497
	Respiratory	–	–

[a] COPD: Chronic Obstructive Pulmonary Disease.
[b] Baseline Incidence per 100,000 is based on threshold limit given in WHO guideline.
[c] Lower and upper limits (range) of the 95% confidence interval of RR values.

Quantification of the health impacts caused by exposure to a particular air pollutant is based on the population attributable-risk proportion (AP) concept. The attributable-risk proportion (AP) is the fraction of health impacts which can be attributed to the exposure in a given population for a certain time period. This model is based on the following formula presentedbelow.

$$AP = \sum[\{RR(c) - 1\} \times p(c)] / \sum\{RR(c) \times p(c)\}, \quad (1)$$

$$RR(c) = (C - T)/\{10 \times (RR - 1) + 1\} \quad (2)$$

$$IE = I \times AP \quad (3)$$

$$NE = IE \times N \quad (4)$$

$$INE = I - IE = I \times (1 - AP) \quad (5)$$

$$\Delta I(c) = (RR(c) - 1) \times p(c) \times INE \quad (6)$$

$$\Delta N(c) = \Delta I(c) \times N \quad (7)$$

To test and apply the above methodology, a case study has been performed to determine the interannaul variation of the excess number of cases in megacity Delhi. The methodology described above depends mainly upon population data and ambient air pollution concentrations. Since we had only the census of 2001 available for population, we have considered population forecasts carried out by the Delhi Planning Commission for other years.

Table 2
Population estimates and annual average concentration of SO_2, NO_2 and SPM in Delhi.

Year	Population	SO_2 ($\mu g\, m^{-3}$)	NO_2 ($\mu g\, m^{-3}$)	SPM ($\mu g\, m^{-3}$)
1998	13,040,000	18	35	361
1999	13,598,000	18	33	362
2000	14,097,000	18	36	405
2001	14,549,000	14	34	348
2002	15,106,000	11	39	443
2003	15,668,000	10	45	352
2004	16,231,000	9	48	357
2005	16,791,000	9	50	330

The results obtained from the above case study using Ri-MAP incorporating the concentration response Eqs. (1)-(7) are shown in Fig. 1(a)-(d). Fig. 1(a)-(d) shows a constant increase from 1998-2002 (apart from the dip in 2001) in the number of excess cases of mortality and morbidity attributed to air pollution in Delhi. After 2002, there is a sharp decrease and then an almost constant trend in both the mortality and morbidity effects of air pollution.

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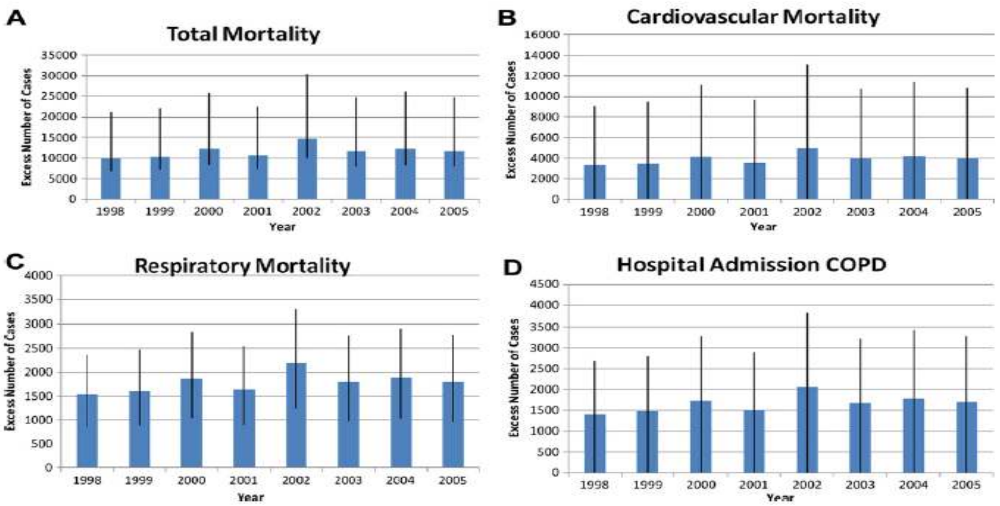

Fig. 1. Excess number of cases 'ΔN(c)' of (a) total mortality, (b) cardiovascular mortality, (c) respiratory mortality, and (d) COPD morbidity (hospital admissions) in Delhi. (Note: In this and subsequent figures, thick bars show estimated values of excess number of cases and thin vertical lines show their lower and upper limits i.e. range for the 95% confidence interval).

To study the possible consequences of (i.e. uncertainty caused by) adopting area specific (e.g., residential/industrial) ambient air pollution concentrations as compared to the city level average concentrations, we have used Ri-MAP to estimate health risks for both the entire city and different areas. The model computes average relative risk estimates along with lower and upper limits (i.e. range) for the 95% confidence interval. In each of the subsequent figures, solid color bars show estimated values of excess number of cases and thin vertical lines show their lower and upper limits i.e. range for the 95% confidence interval. Fig. 2 shows the results for industrial areas (Ind. Av.; average of three station data), residential areas (Res. Av.; average of six station data) and for the entre city (Total Av.; average of nine station data).

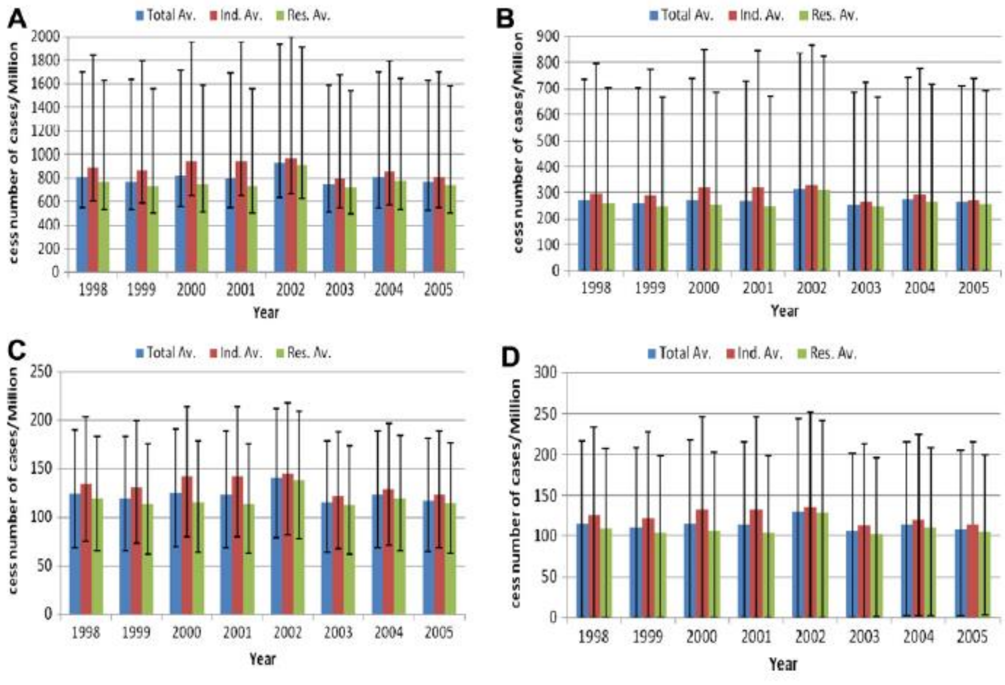

Fig 2. Per million excess number of cases of (a) total mortality, (b) cardiovascular mortality, (c) respiratory mortality, and (d) COPD morbidity (hospital admissions) in different areas (e.g. entire city, industrial area, residential area) of megacity Delhi.

Following the case study of megacity Delhi, we have applied the Ri-MAP model to assess the health risks in different megacities and then rank them according to the levels of air pollution. Table 3 illustrates the population and annual average concentration of TSP, SO2 and NO2 in different megacities used in Ri-MAP to calculate the excess number of mortality and morbidity cases.

Table 3
Population and annual average concentration of TSP, SO_2 and NO_2 in different megacities (Source: Gurjar et al., 2008).

Megacities in 2000	Population × 1000	TSP ($\mu g\ m^{-3}$)	SO_2 ($\mu g\ m^{-3}$)	NO_2 ($\mu g\ m^{-3}$)
Tokyo	34,000	40	19	55
Mexico city	18,500	201	47	56
New York	18,000	27	22	63
Sao Paulo	17,500	53	18	47
Mumbai (Bombay)	16,000	243	19	43
Kolkata (Calcutta)	13,500	312	19	37
Shanghai	13,000	246	53	73
Buenos Aires	12,500	185	20	20
Delhi	12,000	405	18	36
Los Angeles (long beach- Santa-ana)	11,500	39	9	66
Osaka-Kobe	11,500	34	19	45
Jakarta	11,000	271	35	120
Beijing	11,000	377	90	122
Rio de Janeiro	11,000	139	15	60
Cairo	10,500	593	37	59
Dhaka	10,000	516	120	83
Moscow	10,000	150	15	170
Karachi	10,000	668	13	30

Note: 1. Out of 54 (i.e. 18 × 3) observations, sample sizes for different years were as follows: 1990 ($n = 1$), 1992-1994 ($n = 3$), 1995 ($n = 7$), 1998-1999 ($n = 13$), 2000-2001 ($n = 30$).
2. Threshold values for different pollutants considered in calculations; $TSP = 90\ \mu g\ m^{-3}$ (WHO, 1987), $SO_2 = 50\ \mu g\ m^{-3}$ (WHO, 1987, 2000), and $NO_2 = 40\ \mu g\ m^{-3}$ (WHO, 1997, 2000, 2006).

Among the megacities considered (UN, 2004), Tokyo has the largest population, around 34 million and Karachi the smallest with about 10 million. Also, Table 3 shows the annual average ambient air concentrations of the pollutants used in Ri-MAP.

The excess number of deaths, (i.e. total mortality) shown in Fig. 3 has been calculated taking into account the sum total of effects caused by the three criteria air pollutants (TSP, SO2 and NO2). As the Ri-MAP model estimates the effect of pollutants only above the WHO guideline concentrations (WHO, 1987, 1997, 2000), megacities like Osaka Kobe, Sao Paulo, Los Angeles, New York and Tokyo show very low number of excess cases (w60e500). The excess number of cases is highest in Karachi (w15,000/yr), Dhaka (w14,700/yr), Cairo (w14,100/yr), Beijing (w11,500/yr) and Delhi (w10,500/yr). Consequently, these cities are characterized by a greater health risk due to air pollution compared to other megacities.

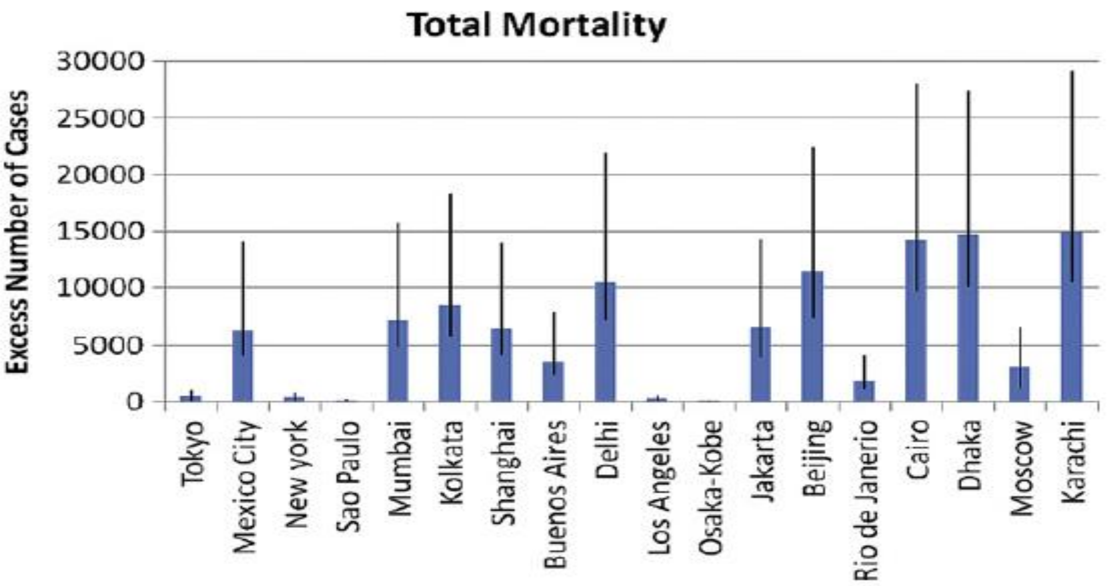

Fig. 3. Excess number of cases 'ΔN(c)' of total mortality/year representative of the late 1990s/2000.

When we consider cardiovascular mortality, even the cities which show no excess cases of respiratory mortality emerge with significant number of excess death cases.This is due to the fact that this category of mortality is related to a high level of NO2 in the atmosphere, and in several megacities the ambient NO2 level exceeds the WHO guideline concentration.

The morbidity (hospital admission) cases due to Chronic Obstructive Pulmonary Disease (COPD) show a pattern similar to that of cardiovascular mortality.

Gurjar et al. (2008) presented a ranking of megacities in terms of air quality based on the Multi Pollutant Index (MPI). This index takes into account the concentrations of different pollutants relative to guideline levels provided by the WHO. It can be inferred from Table 4 that the rankings of most of the South Asian cities like Karachi, Delhi, Kolkata, and Mumbai are higher (i.e. more polluted) in terms of health risks based on the Ri- MAP model than those based on the MPI indices. The MPI provides rankings on the basis of pollutant concentrations whereas Ri-MAP explicitly takes into account the health risks, and incorporates the different relative risks caused by air pollutants.

Table 4
Ri-MAP based ranking of megacities in terms of different categories of mortality, morbidity (COPD) and MPI.

Cities	Total mortality	Cardiovascular mortality	Respiratory mortality	COPD morbidity	MPI
Tokyo	14	14	–	14	16
Mexico City	10	10	8	10	10
New York-Newark	15	15	–	15	14
Sao Paulo	17	17	–	17	17
Mumbai	7	9	7	8	11
Kolkata	6	6	6	6	9
Shanghai	9	8	9	9	8
Buenos Aires	11	12	11	12	13
Delhi	5	5	5	5	7
Los Angeles	16	16	–	16	15
Osaka-Kobe	18	18	–	18	18
Jakarta	8	7	10	7	5
Beijing	4	2	4	4	2
Rio de Janerio	13	13	13	13	12
Cairo	3	4	3	3	3
Dhaka	2	1	1	1	1
Moscow	12	11	12	11	6
Karachi	1	3	2	2	4

We have proposed and applied a straightforward spreadsheet method, the Risk of Mortality/Morbidity due to Air Pollution (Ri- MAP) model. It aims to help estimate human health effects of air pollutants in urban areas (e.g. megacities) by calculating the numbers of excess cases of different types of mortality and morbidity based on international air quality standards.

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