

# Health Risk Assessment of Mobility-Related Air Pollution in Ha Noi, Vietnam

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## ABSTRACT

Hanoi is the capital city of Vietnam and the second largest city of the country, just behind Ho Chi Minh City. During the last two decades, Hanoi developed fast and expanded steadily. Since the city acquired large parts of the surrounding provinces in 2008, Hanoi tripled its size and doubled its population. The new development aims to spread the concentrated population and economic activities to alleviate the stress caused by pollution and the decreasing quality of life of the residents. Hanoi has a very fast growing fleet of motor vehicles, at the rate of 12% - 15% annually. The fast transition from bikes to motorcycles and to cars results in a most serious environmental burden in particular on the air quality and human health. This paper 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 (PM<sub>10</sub> and PM<sub>2.5</sub>). It uses dose-response functions to quantify the number of extra deaths resulting from traffic-related particulate matters. 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 in Southeast Asia. Assessment 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<sub>10</sub>. The result shows that health impacts due to air pollution are by far larger than the number of fatalities due to traffic accidents.

**Keywords:** Hanoi; HIA; Risk Assessment; Traffic-Related Health Effects

## 1. Introduction

Hanoi is the capital of Vietnam and the second largest city 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 3348.5 km<sup>2</sup>; has a population of 6.45 million people with an average density of 1926 people/km<sup>2</sup>, distributed over 27 districts (9 urban and 18 rural) and 408 communes (as of 31 December 2008) [1].

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 [1-3]. In 2006, Hanoi had

an unemployment rate of 6.1%, which reduced to 5.4% in 2008. The city has about 3974 km of roads, of which 643 km 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.

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 [3]. 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 [4]. 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, Bangkok, Beijing, Manila and Jakarta show a 40% - 80% contribution of vehicles to the total concentration of particulate matters [5-12]. 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 [13-18]. Chronic exposure to  $PM_{10}$  is also linked to mortality [18-23].

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 [24] 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 (COPDs) and respiratory diseases.

This paper 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.

## 2. Materials and Methods

### 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 1** 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.

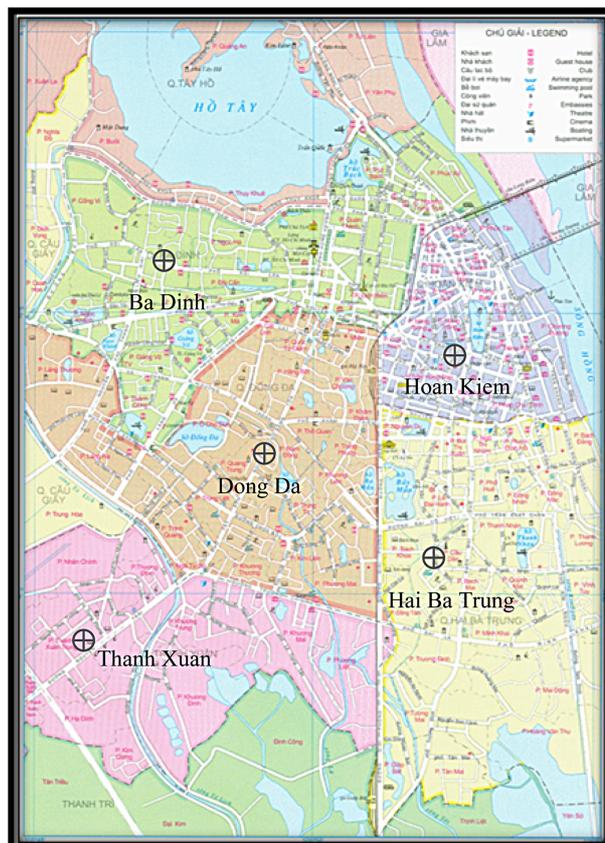


Figure 1. Map of monitoring locations.

### 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 [5,6,17,19-23,25-34]. 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 [18,20,22,23]. These data shown an increase in mortality of 4.3% per 10  $\mu\text{g}/\text{m}^3$  increase in  $\text{PM}_{10}$  (**Table 1**).

- Risk characterisation was assessed based on the number of extra cases of health outcome linked to traffic-attributable air pollution.

For  $\text{PM}_{2.5}$ , the number of restricted-activity days were calculated as proposed by Fisher *et al.* [23] at 9.1 cases per 100 persons per 1  $\mu\text{g}/\text{m}^3$  annual  $\text{PM}_{2.5}$ . The formula for calculation is:

$$N_{\text{RAD}} = E_{\text{PM}_{2.5}} * (9.1 * P_{\text{exp}} / 100) \quad (1)$$

where  $N_{\text{RAD}}$  is the number of restricted-activity days;  $E_{\text{PM}_{2.5}}$  is the annual concentration of  $\text{PM}_{2.5}$  and  $P_{\text{exp}}$  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  $\text{PM}_{10}$ , the number of extra deaths was calculated using the formula [20] that allows to calculate the long-term impact of  $\text{PM}_{10}$  on mortality within the group aged over 30 years old:

$$Po = Pe / (1 + ((RR - 1)(E_{\text{PM}} - B_{\text{PM}}) / 10)) \quad (2)$$

where:

- $Po$  = baseline mortality per 1000 in the age group 30+, after deducting the air pollution effect (this will depend on the other variables).
- $Pe$  = crude mortality rate per 1000 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 Vietnam General Statistical Office [2].
- $E_{\text{PM}}$  =  $\text{PM}_{10}$  exposure level in the area of interest ( $\mu\text{g}/\text{m}^3$ ).
- $B_{\text{PM}}$  = threshold  $\text{PM}_{10}$  exposure level for mortality

**Table 1. Dose-response relationship used in [20].**

Health outcome	Relative risk (RR) <sup>a</sup>	95% CL <sup>b</sup>
Total mortality (adults > 30 years, excluding violent deaths)	1.043	1.026 - 1.061

<sup>a</sup>Relative risk associated with a 10  $\mu\text{g}/\text{m}^3$  increase in  $\text{PM}_{10}$ , <sup>b</sup>95% confidence level.

effect. In this study, with an assumed threshold for  $\text{PM}_{10}$  at 7.5 [23].

- RR = epidemiologically derived relative risk for a 10  $\mu\text{g}/\text{m}^3$  increment of  $\text{PM}_{10}$ , assuming a linear dose-response relationship above the threshold (B) for the age group 30+.

The increased mortality is calculated using the following formula:

$$D_{\text{PM}} = Po * (RR - 1) \quad (3)$$

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

The number of deaths due to  $\text{PM}_{10}$  is calculated as follows:

$$N_{\text{PM}} = D_{\text{PM}} * P_{30+} * (E_{\text{PM}} - B_{\text{PM}}) / 10 \quad (4)$$

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)

## 3. Results

### 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 done by the authors in 2011 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.

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 [33]. 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 2**), 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) [4].

Based on the number of vehicles in circulation, pollution emissions can be assessed. **Table 2** shows the estimation of air pollution emissions from motorised traffic sources in Hanoi.

**Table 2** also 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 3**.

In 2003, daily monitoring data for 365 days show that there were 359 days with PM<sub>10</sub> concentration over 250 g/m<sup>3</sup> [35]. Monitoring results show that the daily concentrations of PM<sub>10</sub> fluctuate with a large difference between day-time and night-time concentrations. During peak hours (around 8 am and 6 pm), the concentrations of PM<sub>10</sub>, CO and NO<sub>2</sub> are highest, showing the impacts of the traffic on air quality. While during night-time (9 pm to 5 am next day), PM<sub>10</sub> concentration is mostly below the standards (QCVN 05:2009), concentrations during

the day are 2 to 3 times higher than the standard [36].

The annual average concentrations of PM<sub>10</sub> are higher than the standards for 3 consecutive years in 2007, 2008 and 2009. For NO<sub>2</sub> and SO<sub>2</sub>, hourly concentrations are within the permissible levels but daily concentrations are higher than the standards.

### 3.2. Health Effects

In this study, the mortality attributed to PM<sub>10</sub> and the morbidity of PM<sub>2.5</sub> 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<sub>10</sub>. The increased mortality due to PM<sub>10</sub> exposure for the group over 30-years is presented in **Table 4**. Only the urban sections of Hanoi are taken into account in the calculation for area and population.

**Table 2. Emission by vehicle types in Hanoi.**

Vehicle type	Travelled distance (km)	Emissions (tonne/year) for 2009				
		TSP	SO <sub>2</sub>	NO <sub>x</sub>	CO	VOC
Motorcycle	5858	1710.21	6.09	2992.88	357007.38	171021.50
Car	6205	69.30	1.01	1178.18	7643.34	821.76
Passenger car and bus	14,600	328.78	0.77	3874.88	1549.95	1244.66
Truck	5475	290.03	0.80	3272.10	7838.16	1446.42
Total		2398.32	8.68	11318.03	374038.83	174534.33

**Table 3. Annual concentration of dust (TSP) in Hanoi at five monitoring stations.**

Year	Average annual TSP concentrations (mg/m <sup>3</sup> )				
	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

**Table 4. Absolute mortality due to PM<sub>10</sub> in the period 2007-2009.**

District	Year	Area	Population	Density	Pop 30+	E <sub>PM</sub>	Po	D <sub>PM</sub>	N <sub>PM</sub>
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 concentrations of  $PM_{10}$  are calculated based on the monitored concentration of TSP (**Table 3**). 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) [37].

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  $7.5 \mu\text{g}/\text{m}^3$ , the estimated number of people dying by non-external causes that may be associated with traffic air pollution is 2785 in 2007, 3007 in 2008 and 3129 in 2009. **Table 4** 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 1000 people in the age group 30+ for each increment of  $10 \mu\text{g}/\text{m}^3$  ( $D_{PM}$ ). 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 5**. 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 Medina *et al.* [22].

**Table 5** 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. 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.

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 more than 3000 extra deaths by traffic related  $PM_{10}$ .

**Table 6** 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" [20]. In Hanoi, this "road-tolls" is much higher than other countries [20,23,38].

**Table 5. Evolution of the number of restricted-activity days during  $PM_{2.5}$  over the period 2008-2009.**

District	Year	Population	$E_{PM}$	$E_{PM_{2.5}}$	$N_{RAD}$	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 6. 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) <sup>a</sup>	58.3	153 per million	501 per million	1:3.3
Austria (1996) <sup>a</sup>	8.1	119 per million	487 per million	1:4.1
Switzerland (1996) <sup>a</sup>	7.1	84 per million	400 per million	1:4.8
New Zealand (2002) <sup>b</sup>	3.7	137 per million	196 per million	1:1.4
Hai Phong, Vietnam (2007) <sup>c</sup>	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

<sup>a</sup>Kunzli *et al.* [20]; <sup>b</sup>Fisher *et al.* [23]; <sup>c</sup>Vu *et al.* [38].

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<sub>2.5</sub> on mortality was not available to be applied in Hanoi. Increasing evidence points to the direction that PM<sub>2.5</sub> is actually the culprit behind mortality due to particulate matter. Therefore, the higher the proportion of PM<sub>2.5</sub>, 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 (NO<sub>x</sub>, SO<sub>2</sub>, VOC) or mental health issues due to noise and traffic disturbances. Those health effects cannot be included in the scope of this paper.

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