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► To cite this version:

Lamri Naidja, Hocine Ali-Khodja, Salah Khardi. Particulate matter from road traffic in Africa. Journal of Earth Sciences and Geotechnical Engineering, 2017, 7 (1), pp.389-304. hal-01453344

HAL Id: hal-01453344

<https://hal.science/hal-01453344>

Submitted on 13 Feb 2017

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Particulate matter from road traffic in Africa

Lamri Naidja¹², Hocine Ali-Khodja¹ and Salah Khardi³

Abstract

In general, much of the air pollution that has adverse impacts on human health and the environment today is the result of anthropogenic activities. Road traffic has led to increase in many air pollutants to levels around the world. It is considered as one of an important source of particulate matter in Africa. Information on PM concentrations and impacts on human health in most African countries are poorly documented, lack of air monitoring network and insufficient number of air quality related researchers may be the reason for the lack of such studies.

A few studies realized in African cities indicate an increasing number of exceedances of WHO guidelines for health related to road traffic. The transport sector has been expanding rapidly. Generally, car fleets are older and poorly maintained, high number of diesel-powered vehicles and all vehicles use low-quality fuels with high lead and Sulphur, which add to traffic-related air pollution.

The objective of this overview aims at describing the atmospheric pollution recorded in many African cities and identifies the contribution of particulate matter from road traffic to the deterioration of the air quality in Africa.

1 Introduction

In 2008, the World Health Organization (2008) reported that 1.3 million annual deaths worldwide are attributable to air pollution, which 82,000 in sub-Saharan Africa. Also has recorded between 2004 and 2008 an increase of 16% in the total number of deaths due to air pollution. Among atmospheric pollutants, particulate

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matter (PM) plays an important role in air quality worsening in urban areas. PM is described in the literature as a mixture of metals, salts, organic compounds from combustion and elemental carbon (Harrison and Yin, 2000; Perrone et al., 2010).

Epidemiological and toxicological research has shown the relationship between particulate matter exposure and human health effects such as cardiovascular diseases (Pope et al., 2009; Brook et al., 2010), mortality and morbidity (Lippmann et al., 2000; Dominici et al., 2004) and lung cancer (Pope et al., 2002; Turner et al., 2011). For regulatory purposes and for estimating health impacts, PM is measured and classified by their aerodynamic diameter into two major categories of particles, PM₁₀ and PM_{2.5} (WHO, 2000). Fine particles smaller than 2.5 µm in diameter (PM_{2.5}) are recognized through epidemiological studies, as being associated with the aforementioned pathologies as well as with asthma especially in children and Chronic Obstructive Pulmonary Disease (COPD) that affects both children and adults (Ebelt et al., 2000, Michael et al., 2013). PM_{2.5} was considered more toxic than the coarse particles (Senlin et al., 2008) with a diameter of less than 10 µm (PM₁₀), which known for their cytotoxic and proinflammatory properties (Jimenez et al., 2002, Bengalli et al., 2013).

As developed countries, protection and regulatory plans were implemented very quickly with the specific objective to reduce emissions of various air pollutants. Most developing countries have long established laws that regulate air emissions to reduce levels of pollution and other impacts on the environment, but few have been successful to improve local air quality (Bell and Russell, 2002). According to WHO (2011) data between 2008 and 2009, populations in countries such as China (150 µg/m³, Lanzhou), South Korea (64 µg/m³, Seoul), Nigeria (122 µg/m³, Lagos), Ghana (98 µg/m³, Accra), Madagascar (68 µg/m³, Antananarivo), South Africa (66 µg/m³, Johannesburg) suffer from high PM₁₀ concentration in ambient air (WHO, 2011).

Van Donkelaar et al. (2015) revealed that 80% of the world's population lives in areas where average annual concentrations of PM_{2.5} exceed highly the WHO guideline's (10 µg/m³). In Africa, the regions most exposed to fine particles (PM_{2.5}) are found in Senegal (38 µg/m³, Dakar), Ghana (50 µg/m³, Accra) and Madagascar (59 µg/m³, Antananarivo) (WHO, 2011).

Figure 1 highlights the high concentrations of PM_{2.5} that extend from North Africa to East Asia. These concentrations of PM_{2.5} recorded in sub-Saharan Africa and Asian continent are much higher than those of Europe, the eastern United States and the West of South America. These high concentrations of fine particles originate mainly from automobile combustion and biomass burning also under the influence of the Sahara desert.

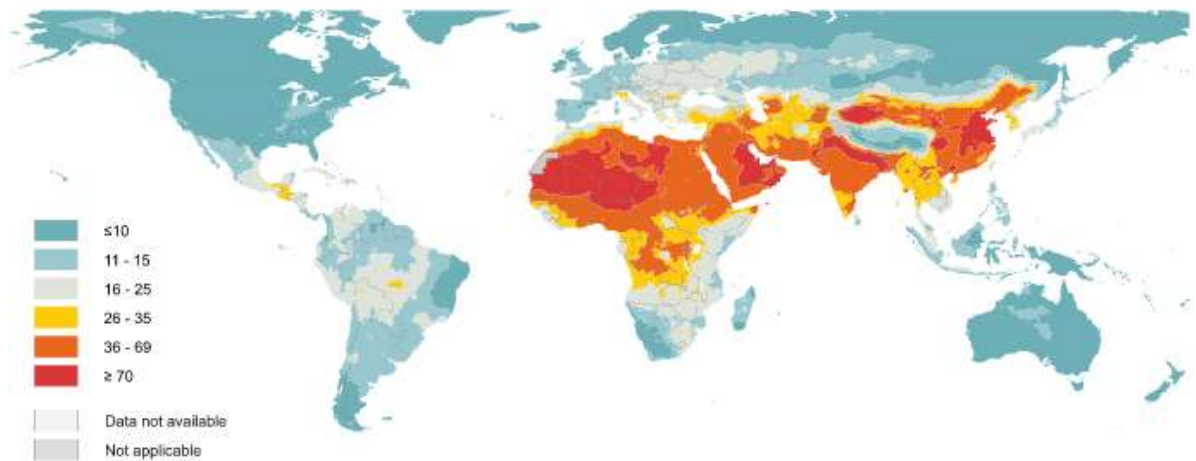


Figure 1: Global annual median concentration of $PM_{2.5}$ in $\mu g/m^3$ (WHO, 2016).

2 Overview of transport sector in Africa

The use of automobiles has considerably increased with urbanization throughout the world, urban transport plays a critical role in the development of urban areas and overall economic growth but it also results in negative factors such as air pollution (Mieszkowski and Mills, 1993). Over the last few decades the demographic and urban growth and industrial development have accelerated the use of motorized vehicles namely in developing countries (Sharma et al., 2011; OECD, 2010).

Although the number of road motor vehicles per 1000 inhabitants is the least in Africa compared to other regions (Davis et al., 2013). Outdoor PM levels from road traffic in Africa are generally much higher than in developed countries. One of the possible explanations is the large numbers of engine vehicles powered by diesel (Brunekreef, 2005), which generate ten times more particles than gasoline vehicle per kilometer driven (Rallis, 1988; Krupnick, 1991). Car fleets are older and poorly maintained, which adds to traffic-related air pollution (Panyacosit, 2000).

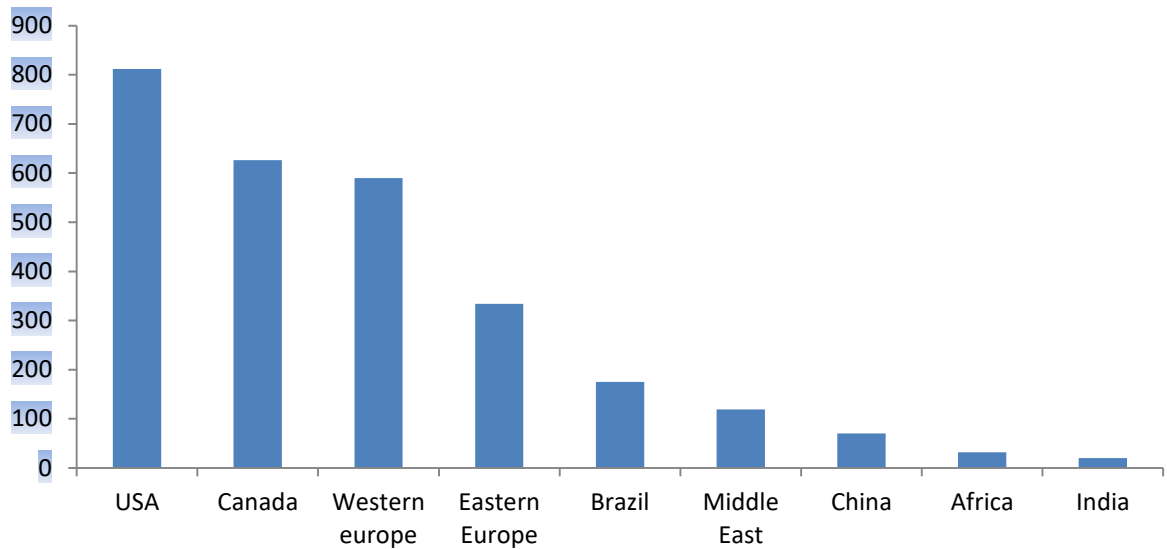


Figure 2: Vehicles per thousand people in 2011 in the world (Davis et al., 2013)

But, over the last decade, motor vehicles numbers have been doubling in Africa (see Fig. 3). The total number of motor vehicles increased from 25.996 million in 2005 to 42.511 million in 2014, with an average growth rate of 4 % per year in the continent, most of this growth in vehicle holdings comes from imports of used vehicles (OICA, 2014).

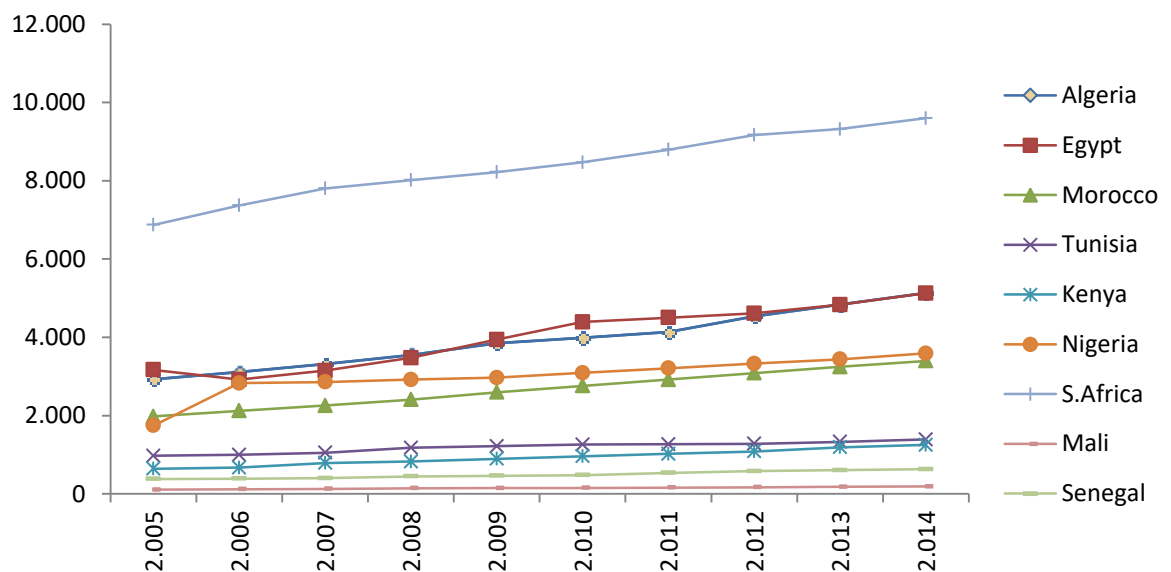


Figure 3: Increase in vehicle fleet in African countries between 2005 and 2014 (in thousand units) (OICA, 2014)

High rate of urbanization combined with low-income individual, has resulted in the rapid increase in the import of older used vehicles (Fourn and Fayomi, 2006). The Algerian vehicle fleet consists essentially of passenger vehicles (64%), trucks (almost 20%), motor coaches and buses (1.52%) and others. Most of the fleet is not equipped with catalytic converters (ONS, 2014). In 2013, the transport sector ranked first in energy consumption, 41% and 65 % of vehicle fleet run is diesel vehicles (UNEP, 2015a). Air pollution in Cairo has become an increasingly serious issue. Cairo is ranked in the 33rd on the list of the most polluted cities by PM₁₀ (WHO, 2014); road traffic emissions accounted for 32% of particulate matter (USAID, 2004). According to the Central Agency for Public Mobilization and Statistics of Egypt the total number of vehicles was around 7 million in 2013, and approximately half of them were in Cairo. Public transportation accounted for 68% of all vehicles while buses contributed to 82% of all public transportation. Almost all buses and taxis use diesel as a fuel and old generation diesel engines without catalytic converters or diesel particle filters, and about 90,000 taxis in Egypt are over 20 years old (CAPMAS, 2014). The Kenyan fleet vehicle in 2004 was composed of light-duty trucks (35%), passenger cars (29%), heavy-duty trucks (7%) and minibuses (7%). Most trucks and buses use sulphur-rich diesel (KNBS, 2007).

In Cotonou, the economic capital of Benin, poor air quality has recently been reported (Cachon et al., 2014). The increase in recorded air pollution is mainly due to urbanization (UN, 2010), the lack of public transport and the use of highly polluting mopeds (aged over 15 years) (Gounougbe, 1999; Avogbe et al., 2011). In 2002, it is estimated that more than 94,000 mopeds and 350,000 used vehicles are in circulation in Cotonou (MMEH, 2002).

Several studies have shown the clear relationship between automobile traffic density, the use of leaded gasoline and lead content in the air and soil in urban zones (Caprio et al., 1974; Heinze et al., 1998; Lanphear et al., 1998).

US EPA began to ban the use of leaded gasoline in the 70's (Harrington and McConnell, 2003). In 1996, World Bank is calling for the elimination of leaded gasoline. After that, the European Union adopted new laws progressively to ban petrol containing lead for the period 1998–2005 (O'Brien and Partner, 2011).

Africa like the Middle East remains the exception, motorized vehicles still run exclusively on leaded gasoline. In 1993, lead emissions from vehicles in Africa were estimated over 13 million tons, which represent quarter of the global annual lead emissions (Bultynck and Reliquet, 2003). In most African countries, gasoline contains between 0.5 and 0.8 g/l lead, which is among the highest levels in the world (Tong et al., 2000)

Thus, in Senegal like in many African countries, a rapid uncontrolled growth of the automobile fleet can be seen and could be the origin of negative effects on

health particularly in cities (UNEP, 2015b). Studies carried out in Dakar show that lead content in the barks of trees bordering the highways is due to traffic intensity (Diouf et al., 1994). These results therefore show that the use of leaded gasoline is the main cause of air contamination and could be one of the principal sources of exposure to the public especially in children who constitute the most vulnerable group.

The greater increases in public transport demand for the major sub-Saharan Africa cities encourage the use of the two-wheels (Motorcycle-taxi) as a mean of transportation owing to cheaper but highly polluting fuels (Godard and Ngabmen, 2002; Diaz Olvera et al., 2007). It estimated to emit more than 10 times of fine particulate matter per kilometer travelled than a modern car, and only a little less than a light diesel truck (Weaver and Chan, 1996). Assamoi and Liousse (2010) indicated that these vehicles are strong emitters of particles, especially in Togo, Benin, Burkina Faso, Mali and Nigeria where fuel uses a mixture of gasoline and oil (Wane et al., 2001; Diallo, 2001). Non-motorized transport, including walking is also a transportation mode in sub-Saharan Africa cities which accounts for 50% of all trips, whereby citizens are exposed to highly polluted air throughout the day (Gwilliam, 2003).

African countries suffer from weak traffic planning and management and low funding for routine and periodic rehabilitation of roads (Riverson et al., 1991; Pedersen, 2001, Armah et al., 2010), which affect traffic flows and travel speeds. The traffic congestion has an important part to the deterioration of urban air quality by multiplying emissions per kilometer travelled (Chin, 1996; Smit et al., 2008; Armah et al., 2010).

According to Japanese International Cooperation Agency (2006) that estimated the increase in vehicle fleet by 148% in Nairobi between 2004 and 2025 which implies decrease of an average speed of trips from 35 km/h to 11 km/h as congestion increases, that if nothing is changed regarding road infrastructures.

In Accra, the road congestion is a serious problem, 70% of major roads operating classified in poor conditions, speed traffic flow is considered of less than 20 km/h and about 1.34 million passenger trips per day by public transport (Armah et al., 2010). A similar situation exists in Zimbabwe, according to the World Bank (2008), by 2005, road network in poor condition exceeds 40 % and only 24% was in good condition due to increase in vehicle fleet and lack of road maintenance.

3 Levels of PM in African cities from road traffic

African cities are poorly equipped to absorb such a rapidly growing population. The lack of infrastructure has brought on severe problems. Vehicles are major

sources of air pollutant emissions especially in urban areas. These various pollutant emissions depend on the daily kilometers traveled (Beevers and Carslaw, 2005; Batterman et al., 2014), the fuel composition (Nelson et al., 2008; Johansson et al., 2009), the age of the vehicle fleet (Zachariadis et al., 2001), and also the composition of the fleet (Sternbeck et al., 2002).

In the framework of the Clean Air initiative project in sub-Saharan Africa, studies conducted in Dakar and Ouagadougou show that the emissions of NO_x , SO_2 and PM_{10} in Dakar are higher than level found in Ouagadougou, due to the use of public buses and an old vehicles fleet which motorized by diesel. On the other hand, in Ouagadougou, 86 % of motorized trips depend on mopeds fueled by gasoline, that don't carry more than one passenger means high level emissions of carbon monoxide (CO) and hydrocarbons (HC) compared to Dakar and low emissions of NO_x , SO_2 and PM_{10} (Schwela, 2012).

Table 1: shows the ranges of mean PM_{10} , $\text{PM}_{2.5}$ and TSP levels obtained for recent studies realized in African cities.

Location	Periods	Fractions measured	Mean concentrations ($\mu\text{g}/\text{m}^3$)	Site description	Main sources	References
Constantine, Algeria	23 March 2011 to 22 November 2011	PM_{10}	80.42	Traffic site	Road traffic sea salt and soil resuspension	Terrouche et al. (2016)
	23 December 2011 and 8 January 2013	PM_{10} $\text{PM}_{2.5}$	105.2 57.8			
Algiers, Algeria	2010, 2011 and 2012 (14 months)	TSP	34.8	Suburban	Road traffic	Bouhila et al. (2015)
Kenitra, Morocco	June 2007 and May 2008	PM_{10} $\text{PM}_{2.5}$	115.12 51.32	Traffic site	road traffic, dust resuspension	Zghaid et al. (2009)
Shobra, Egypt	June and October 2010	PM_{10} $\text{PM}_{2.5}$	154 to 360 61 to 216	Industrial and residential	Road traffic, industry, resuspended soil	Lowenthal et al. (2014)
Sapele, Nigeria		PM_{10} $\text{PM}_{2.5}$	104.17 to 434.03 104.17 to 260.42	Industrial and commercial	Road traffic, industry and Biomass burning	Ediagbonya et al. (2015)

Bamako, Mali		PM	205.8	Residential and traffic site	Road traffic, biomass burning	Val et al. (2013)
Dakar, Senegal		PM	80.7			
Harare, Zimbabwe	July to December 2002	TSP PM ₁₀ PM _{2.5}	106.11± 21.41 59.70± 13.48 40.55± 11.43	Industrial site	Road traffic, industry	Kuvarega and Taru (2008)
Addis Ababa, Ethiopia	22 February 2008 to 15 April 2008 17 June 2008 to 23 July 2008	TSP PM ₁₀	195±141 80±61	Urban	unpaved road, construction works	Gebre et al. (2010)

The daily PM₁₀ levels recorded in Constantine, Algeria, between March 2011 to November 2011 were reported by Terrouche et al. (2016) at 80.42 µg/m³. In another sampling campaign during 23 December 2011 to 8 January 2013, average concentrations of PM₁₀ (105.2 µg/m³) and PM_{2.5} (57.8 µg/m³) greatly exceeded both the Algerian limit and the WHO guideline values. Traffic and industry were considered as the main source in the region.

During 2010, 2011 and 2012 (14 months), PM levels were measured in Draria city, a suburban site near Algiers, and the mean TSP concentration was 34.8 µg/m³, these excessive levels were attributed to intense traffic (Bouhila et al., 2015)

According to study carried out by Zghaid et al. (2009) during the period between June 2007 and May 2008, in Kenitra city which is located 50 km north of Rabat, the average PM₁₀ and PM_{2.5} concentrations were 115.12 µg/m³ and 51.32 µg/m³ respectively. The major sources of pollution in this region were attributed to road traffic and dust resuspension.

Lowenthal et al. (2014) studied the data collected from the ambient air quality stations located at 5 Cairo different sites during June and October 2010. The concentrations of PM₁₀ and PM_{2.5} were higher in October than June in the five sites excepted at the residential site of Helwan. Shobra recorded high daily concentrations for PM₁₀ and PM_{2.5} which ranged from 154 to 360 µg/m³ and 61 to 216 µg/m³ respectively, due to heavy traffic and industrial activities in the area. Lower concentrations for the two PM fractions were observed during summer at the residential area of El-Zamalek and the urban background site of Kaha, whereas Helwan was located nearby a cement plant and heavy traffic. The main source of

PM₁₀ was resuspended soil, exhaust emissions from vehicle, and agricultural waste open air incineration, while PM_{2.5} was mostly due to exhaust gases.

Ediagbonya et al. (2015) carried out a measurement campaign during the wet season at Sapele town located in Southern Nigeria which is characterized by a petrochemical plant and commercial activities. The samples collected by a high volume gravimetric sampler in ten different locations indicated high levels of PM₁₀ and PM_{2.5} which ranged from 104.17 to 434.03 µg/m³ and 104.17 to 260.42 µg/m³ respectively, due mainly to traffic and burning wood used as a fuel.

Val et al. (2013) reported that daily PM mean levels at Bamako city and Dakar city reached 205.8 µg/m³ and 80.7 µg/m³ respectively; these high concentrations are mainly due to traffic emissions and biomass burning used for cooking and heating purposes.

Gebre et al. (2010) collected samples from seven sites in Addis Ababa, during the period extending from 22 February 2008 to 15 April 2008 and from 17 June 2008 to 23 July 2008. They reported that the mean TSP and PM₁₀ concentrations were 195±141 µg/m³ and 80±61 µg/m³ respectively. The observed average TSP and PM₁₀ concentrations during the dry season were 304±102 µg/m³ and 107±68 µg/m³ respectively whereas during the wet season, the average concentrations were 75±5 µg/m³ and 43±21 µg/m³ respectively. The high PM levels were attributed to unpaved road and construction works around all sites and the variance of concentrations for the two seasons can be explained by rainfall scavenging of aerosol during the wet season. In another study, Kuvarega and Taru (2008) conducted an atmospheric measurement campaign of particulates, from July to December 2002, near an industrial site in the city of Harare, Zimbabwe. The average concentrations of TSP, PM₁₀ and PM_{2.5} were 106.11± 21.41, 59.70± 13.48 and 40.55± 11.43 µg/m³ respectively; elemental analysis showed high levels of Co and Ni originating from the thermal power station, whereas the presence of lead and cadmium was linked to heavy traffic in the area especially during rush hours in the morning and in the evening.

4 Conclusion

In the African countries, air pollution appears as a public health problem. The health consequences of this pollution are currently causing concern among the population and decision makers. There is little data available to raise public awareness and to convince the authorities of the urgent actions to be taken to curb the phenomenon.

Choice and use of fuels for motorized transportation still remains an issue to be solved in Africa, and particularly in countries where there is a high utilization of

two-wheeled motor vehicles. The first priority clearly is to phase-out the addition of lead to gasoline to reduce urban air pollution and improving the quality of life in African cities. The use of catalytic converters on vehicle exhaust systems reduces greatly the emissions of several airborne pollutants from vehicles, including lead.

The introduction of alternative fuels such as compressed natural gas (CNG) and liquefied petroleum gas (LPG) in taxi and buses, which are available in abundance in many African countries, is an efficient solution to improve urban air quality.

Electric vehicles are already being used in many developed countries, which have obvious attractions such as urban vehicles also to be economically viable at the individual level; they may thus combine environmental and economic benefit.

Technical control and maintenance of vehicles may also reduce emissions significantly.

Promotion of public transport by building metros in large cities and develop tram rails in suburban zones, these investments are high initially but become cost effective in the medium term especially in high density cities where one metro line can transport more people than ten 3-lane highways.

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