Vehicular Air Pollution - Sources and Adverse Effects

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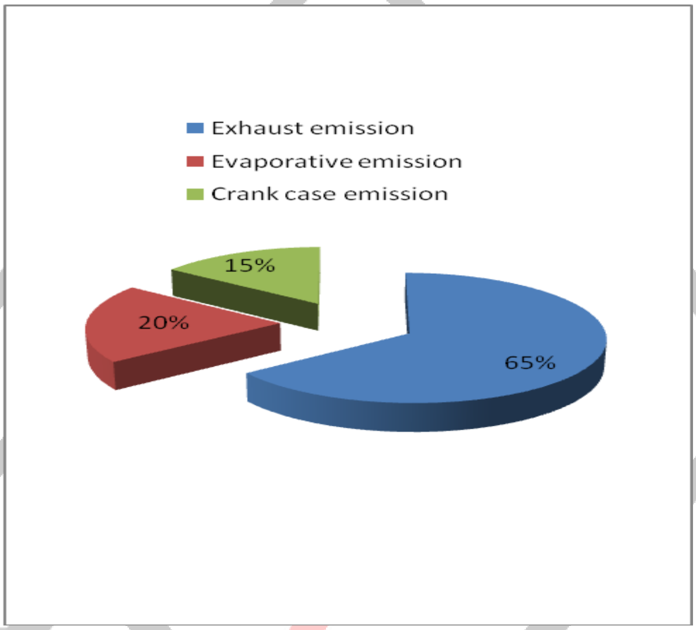
Sources of vehicular air pollution:

There are three main sources of automobile air pollution and the percentage of emissions from each source is given hereunder:

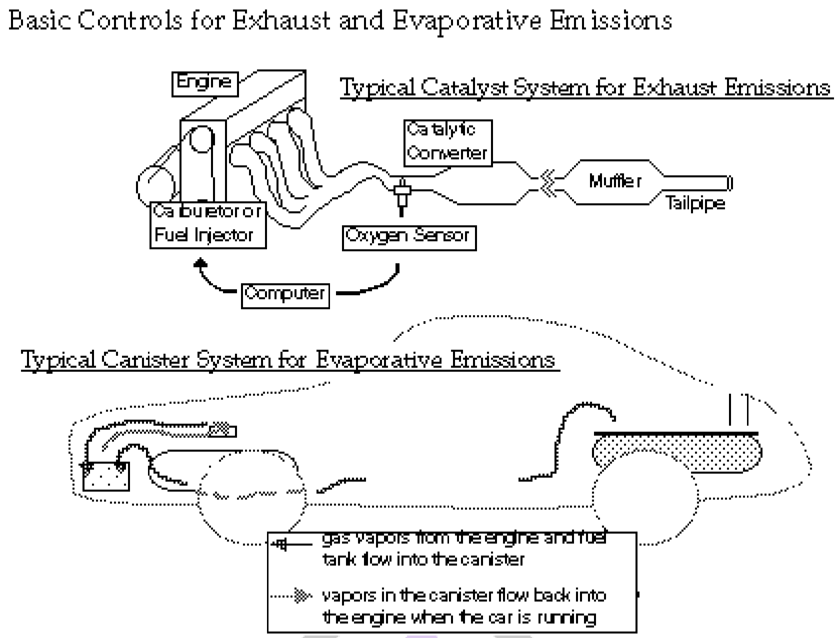
1) Exhaust emission-60%
2) Evaporative emission-15%
3) Crankcase emission-20 %



Graph 1: Percentage of Sources of vehicular air pollution

Exhaust emission:
Complete combustion of hydrocarbon fuel yields to CO_2 and water only as the products of chemical combination. The exhaust produces many air pollutants including sunburnt hydrocarbons, CO, NOx, and lead oxides. Exhaust contains traces of other polluting gases like aldehydes, esters, ethers, peroxides and ketones. Some of the factors influencing absolute and relative concentrations of combustion products are air-fuel ratio, ignition timing, absolute charge density, combustion chamber geometry and variable engine parameters such as speed, load and engine temperature.

Evaporative emissions:
10-30% of the hydrocarbons in vehicular emission belong to this category. Two main sources of evaporative emissions are the fuel tank and the carburetor. Fuel tank losses consists volatile fractions of gasoline displaced from vapor space above the liquid fuel in the gas tank. Carburetor emissions may be divided into two categories: 'Running' losses occurring during the engine operation and 'hot soak losses' occurring when the vehicle is parked. The fuel volatility and carburetor design affect the carburetor emissions. The evaporation through the carburetor occurs primarily when engine is stopped and heat builds up. Almost 12-40ml. of fuel is lost during each long haul stop causing emission of hydrocarbons.



Crankcase emissions:

Crank case blow-by, accounts for about 1/5th of the hydrocarbons in all vehicle emissions. For air pollution, blow-by also equally is most important. The quantity of blow-by depends on engine design and operating variables and it may be enhanced by poor engine maintenance and by use of crankcase oils.

Pollutants in Gasoline Vehicles Emissions:

Emissions from Gasoline Vehicles primarily consisting of CO, HC, oxides of nitrogen (NOx), SO2, and partial oxides of aldehydes, besides particulate matters including Pb salts account for the larger chunk of all pollution from gasoline-run vehicles. Gasoline powered engines are of two types- four stroke and two stroke. Table below gives various sources of emissions in the two cases.

Table: 1 Sources of Emissions from Gasoline Vehicles

Sources	Amount of Emissions (%)		Remarks
	4 stroke	2 stroke	
Crankcase blow by	20	--	Carbureted air fuel mixture and combustion fuel under pressure escape the combustion chamber past the engine piston and ring and enter the crankcase to be discharged into atmosphere through vents.
Evaporative Emissions	20	3	Fuel vapor lost to the atmosphere from tanks and carburetor
Exhaust Emissions	60	97	Exhaust gases emitted with pollutants trough tailpipe.

The incomplete combustion of gasoline due to an imbalance in the air-fuel ratio leads to emissions of CO and HC especially from 2-stroke engines. The Nox, however, are formed due to high combustion temperature and availability of oxygen and nitrogen in the combustion chamber, whereas aldehydes result from the partial oxidation of HC. In cities, majority of the pollution is emitted by vehicles consuming gasoline − especially 2 and 3-wheelers, having predominantly 2-stroke engine.

The 2-stroke 2- and 3-wheelers require 2 T oil for lubrication of engine, which is carried out through either premixing mode or oil injection system. In either case it is a total loss system, as the oil is burnt along with the fuel. Since the burning quality of mineral based lubricating oil is very poor vis-à-vis gasoline, major fraction of it that enters the engine either remains unburned or burns only partially. This unburned and partially burned oil comes through the exhaust and is responsible for smoke and SPM emission. The studies indicate that 2-stroke engine's exhaust contains almost 15-25% of unburned fuel (Pundir, 2001). In actual practice, the 2-stroke vehicles require 2% concentration of 2 T oil i.e., 20 ml in a litre of petrol and even a modest 1% increase of oil, may lead to 15% increase in SPM besides visible smoke (CPCB, 1999). In most growing cities − Delhi, Kathmandu, Chennai, Dhaka, Pune etc. − gasoline or petrol driven vehicles comprise over 80% of the total vehicles registered. This implies controlling pollution from them can have significant pay-offs.

Pollutants in Diesel vehicles Emissions:

Diesel engines breathe only air, blow by gases from the crankcase (consisting primarily of air and HC) are rather low. Moreover, due to its low volatility, evaporative emissions from the fuel tank can safely be ignored. Though the concentration of CO and un-burnt HC in the diesel exhaust are rather low, they are compensated by high concentration of NOx (higher than that in gasoline vehicles). There are smoke particles and oxygenated HC, including aldehydes and odor-producing compounds which have high nuisance value.

Smoke from diesel engines comes in three different hues – white smoke emitted during cold start idling and at low loads; blue smoke from the burning of lubricating oil and additives; and black smoke, a product of incomplete combustion. Black smoke, the most obvious type of vehicular air pollution, consists of irregular shaped agglomerated fine soot/particulates, the formation of which depends on injector nozzle parameter and type of combustion chamber (direct or indirect injection). Black smoke is a particular problem with diesel engines that are not well tuned, which is often the case in the developing world.

Impact of (Gasoline and Diesel) Fuel Quality on emissions:

Much of the pollution control depends on the quality of the fuel. So the characteristics that determine fuel quality also become important. A high Reid pressure 8 in the case of gasoline engine causes a high evaporative emission while an increase in the density results in a simultaneous increase in CO and HC in the exhausts. Likewise in the case of diesel vehicles, a higher density causes higher smoke, CO and NOx emissions, while enhancing the cetane number9 of ignition quality lowers the smoke emission. The sulphur content of diesel has been observed to have a direct bearing on the SPM and SO2 emissions (CPCB, 1999).

Pollutants from Diesel vis-à-vis CNG Run Engines:

The combustion of fuels release SO2, NOx, CO and ozone. The CO is highly noxious gas that forms when there is not enough oxygen during the combustion. The CO, however, oxidizes very fast and forms CO2, which though is not noxious but is one of the major contributors of greenhouse effect. This implies a reduction of CO, hence CO2 emissions, can only be achieved by improving the engine efficiency or by using fuels containing lower concentration of carbon such as natural gas.

The compressed natural gas (CNG) is a clean-burning alternative fuel for vehicles10 with a significant potential for reducing harmful emissions especially fine particles. Nylund and Lawson (2000) find that diesel combustion emits 84 grams per kilometer (gms/km) of such components as compared to only 11 gms/km in CNG. The levels of greenhouse gases emitted from natural gas exhaust are 12% lower than diesel engine exhaust when the entire life cycle of the fuel is considered (ibid.). It has also been found that one CNG bus achieves emission reduction equivalent to removing 85-94 cars from the road. Table 2 gives the emission benefits of replacing conventional diesel with CNG in buses.

Table 2: Pollution Benefits of Replacing Conventional Diesel with CNG in Buses

Fuel	Pollution Parameter		
	CO	NOx	PM
Diesel	2.4 g/km	21 g/km	0.38 g/km
CNG	0.4 g/km	8.9 g/km	0.012 g/km
% Reduction	84	58	97

Diesel with sulphur content of 10 ppm (also called as 'clean diesel') is environmentally viable only when it is combined with other technology such as the state of the art exhaust treatment devices like continuously regenerating particulate traps (CRTs). Incidentally the devices are also highly maintenance intensive.

Apart from the fact that CNG does not contain polyaromatic hydrocarbons (PAHs), airborne toxins and SO2, CNG run vehicles have more quiet operation, less vibrations and odor than equivalent diesel engines. However, high vehicle cost, shorter driving range, heavy fuel tank, expensive distribution and storage network and potential performance and operational problems compared to liquid fuels are some of the drawbacks of using CNG vehicle (Watt, 2001 as referred in World Bank, 2001b).

Emissions caused by Congestion:

Congestion engenders a double effect. First the time cost of a vehicle kilometer rises rapidly with increased congestion. This is because the addition of a vehicle to an already crowded network increases travel time for many other passengers. Since the average speed has reduced to levels that are far below the optimal operating vehicles speed, this leads to increase in rate of emissions per kilometer – thus the two effects are inter-related (Johansson, 1997). The congestion has costed nearly US$ 14 billion in terms of excess time required and gasoline consumed to the commuters in California, in addition to substantial environmental damage (Sterner, 2002: 233). Krawack (1993)11 states that a reduction from 40 km/h to 20 km/h doubles the emissions of CO and volatile organic compounds (VOCs) for a car fitted with a catalytic converter. Since VOCs and CO are 250% higher under congested conditions than during free-flowing traffic, poor air quality is the consequence.

Typical factor affecting motor vehicle emission rate:

Table 3: Factor effecting vehicle emission rate:

Vehicle parameter	Fuel parameter	Vehicle operating condition	Environmental parameter
• Vehicle class • Model-year • Fuel delivery system • Emission control system • Onboard computer control system • Control system tampering • Inspection and maintenance history	• Fuel type • Oxygen content • Fuel volatility • Sulfur content • Benzene content • Olefins and aromatic HC content • Lead and metal content	• Average vehicle speed • Load(such as air conditioner, heavy loads) • Cold or hot start mode	• Altitude • Humidity • Ambient temperature • Diurnal temperature changes

Health and environmental effects of vehicular pollutants:

General/Overall Effects:

The vehicular emissions have damaging effects on both human health and ecology. There is a wide range of adverse health/environmental effects of the pollutants released from vehicles. The effects may be direct as well as in-direct covering right from reduced visibility to cancers and death in some cases of acute exposure of pollutants specially carbon monoxide. These pollutants are believed to directly affect the respiratory and cardiovascular systems. In particular, high levels of Sulphur dioxide and Suspended Particulate Matter are associated with increased mortality, morbidity and impaired pulmonary function. The overall effects of vehicular emissions are summarized in table 1. The pollutant wise health effects are summarized in table 2

Table-4: Vehicles emit significant amounts of several pollutants with varying effects as summarized:

	Health Effect					Climate Change	
Pollutant	Direct	Indirect	Acid rain	Eutrophication	Visibility	Direct	Indirect
CO	X						X
HC	X	X[a]					X
NOx	X	X[a]	X	X	X	X	
PM	X				X	X	
Sox	X		X		X		X

CO = carbon monoxide, HC = hydrocarbon, NOx = nitrogen oxides, PM = particulate matter, SO2 = sulfur oxide, X[a] Ozone

Health effects due to vehicular emission:

Table: 5 Effects of Human health on vehicular air pollutants:

Pollutant	Effect on Human Health
Carbon Monoxide	When Carbon Monoxide is inhaled, the CO combines with the hemoglobin to form carboxyhemoglobin (COHb). CO displaces oxygen attached to the carrier molecule, hemoglobin. The COHb bond is over 200 times stronger than oxygen's bond with hemoglobin. The strong COHb bond makes it difficult for the body to eliminate CO from the blood. It reduces the oxygen carrying capacity in the blood. Affects the cardio vascular system, exacerbating cardiovascular disease symptoms, particularly angina; may also particularly affect fetuses, sick, anemic and young children, affects nervous system impairing physical coordination, vision and judgments, creating nausea and headaches, reducing productivity and increasing personal discomfort.
Nitrogen Oxides	Inhibits cilia action Respiratory problems, Increased susceptibility to infections, pulmonary diseases, impairment of lung function and eye, nose and throat irritations.
Sulphur Dioxide	Headache, Vomiting, Respiratory problems, chest congestion, Affect lung function adversely.
Particulate Matter and Respirable Particulate Matter (SPM and RPM)	Fine particulate matter may be toxic in itself or may carry toxic (including carcinogenic) trace substance, and can alter the immune system. Fine particulates penetrate deep into the respiratory system irritating lung tissue and causing long-term disorders.
Lead	Impairs liver and kidney, causes brain damage in children resulting in lower I.Q., hyperactivity and reduced ability to concentrate. Lead interferes with normal red blood cell formation by inhibiting important enzymes. In addition, lead damages red blood cell membranes and interferes with cell metabolism in a way that shortens the survival of each individual cell. Each of these harmful effects can result in anemia.
Benzene	Both toxic and carcinogenic. Excessive incidence of leukemia (blood cancer) in high exposure areas. Long-term exposures to benzene may affect normal blood production, leading to anemia and internal bleeding. In addition, human and animal studies indicate that benzene is harmful to the immune system, increasing the chance for infections and perhaps lowering the body's defense against tumors. Exposure to benzene has also been linked with genetic mutations in humans and animals.
Hydrocarbons	Hydrocarbons react in the presence of nitrogen oxides and sunlight to form ground-level ozone, a major component of smog. Ozone irritates the eyes, nose, and throat and damages the lungs. A number of exhaust hydrocarbons are also toxic, Potential to cause cancer.
Formaldehyde	Aldehyde are absorbed in respiratory and gastrointestinal tracks and metabolized. Once metabolized they are excreted from the human body. Adverse health effects of Formaldehyde include eyes and nose irritation (at concentration of 0.06 mg/m^3), irritation of mucous membrane and alteration in respiration (at concentration of 0.12 mg/m^3), coughing, nausea, and shortness of breath. The threshold for tissue damage is about 1mg/m^3. Occupational exposure to formaldehyde is associated with risk to cancer
PAH	PAHs can enter the body through the lungs. PAHs enter the body quickly and

	easily by all routes of exposure. The rate at which PAHs enter your body is increased when they are present in oily mixtures and tend to be stored in the kidneys, liver, and fat, with smaller amounts in the spleen, adrenal glands and ovaries. Results from animal studies show that PAHs do not tend to be stored in for a long time and are excreted within a few days in the feces and urine.

Pollutants specific health effects in details:

There is a wide spectral of adverse health/environmental effects of the pollutants released from vehicles. The effects may be direct as well as in-direct cover right from reduce visibility to cancers and death in some cases of acute exposure of pollutants specially carbon monoxide. Pollutant specific health effects of vehicular emissions are as below:

Carbon monoxide (CO)
Carbon monoxide (CO is an odorless, invisible gas created when fuels containing carbon are burned incompletely) poses a serious threat to human health. CO is known to cause death at high levels of exposure. The affinity of blood hemoglobin is 200 times greater for carbon monoxide than for oxygen, CO hinders oxygen transport from the blood into the tissues. The effects of this gas in human have been shown even at low level of exposure. The low level of exposure accelerate and angina (chest pain) in people having coronary artery diseases. Healthy individuals are also affected, but only at higher levels. .Exposure to elevated CO levels is associated with the impairment of visual perception, work capacity, manual dexterity, learning ability and the performance of complex tasks.

Nitrogen Oxides:
Nitrogen dioxide (NO_2) has been linked with increased susceptibility to respiratory infection, increased airway resistance in asthmatics, and decreased pulmonary function. It has been shown that even short-term NO_2 exposures have resulted in a wide-range of respiratory problems in school children; cough, runny nose and sore throat are among the most common. The oxides of nitrogen also contribute to acid deposition on plans and surface water resulting into damages of trees and aquatic life. NO_x emissions also increase the levels of particulate matter by changing into nitric acid in the atmosphere and forming particulate nitrate.

Photochemical Oxides (Ozone):
There is no release of ozone as such from the vehicles but it is formed as a result of chemical reactions of volatile compound and NO_x in the presence of heat and sun light. In other words, the pollutants release from vehicles also results into formation of ozone through chemical reactions. The ground level ozone which is the main part of the smoke can cause respiratory problems such as chest pain, cuffing etc. The ozone gas is known to cause inflammation respiratory tracks, reduction in the ability to breath (lung function), increase in asthma and other lung diseases.

In addition to effects on human health, ozone is also known to adversely affect the environment in many ways including reduce yield for crops, fruits, commercial forests, eco-system etc. It also damages urban grass, flowers, shrubs and trees etc.

Oxides of Sulphur:
High concentrations of sulfur dioxide (SO_2) can result in temporary breathing impairment for asthmatic children and adults who are active outdoors. Short-term exposures of asthmatic individuals to elevated SO_2 levels while at moderate exertion may result in reduced lung function that may be accompanied by such symptoms as wheezing, chest tightness, or shortness of breath. Other effects that have been associated with longer-term exposures to high concentrations of SO_2, in conjunction with high levels of PM, include respiratory illness, alterations in the lungs' defenses, and aggravation of existing cardiovascular disease

Gaseous Air Toxic:
The hydrocarbons emissions release from vehicles also contained toxic air pollutants that may have a significant effect on public health.

Benzene:
Benzene is a known human carcinogen by all routes of exposure. Low term respiratory exposure to high level of ambient benzene has been shown to cause cancer all the tissues that formed white blood cells. Exposure to benzene or its metabolites has also been linked with genetic changes in human and animals. The occurrence of certain chromosomal changes in individuals with known exposure to benzene may serve as a marker for those at risk of contracting leukemia.

Formaldehyde:
Formaldehyde has been classified as a probable human. Epidemiological studies suggest that long-term inhalation of formaldehyde may be associated with tumors of the nasopharyngeal cavity (generally the area at the back of the mouth near the nose), nasal cavity, and sinuses. Formaldehyde is also known to produces mutagenic activity.

1, 3-Butadiene:
1,3-Butadiene has also been classified as a Group B2 (probable human) carcinogen based on evidence from two species of rodents and epidemiologic data.

Lead:
Lead affects many organs and organ systems in the human body, with sub-cellular changes and neurodevelopment effects appearing to be the most sensitive. Lead also causes impaired sensory motor function and renal functions. A small increase in blood pressure has also been associated with lead exposure. Airborne lead can be deposited on soil and water, thus reaching humans through the food chain and drinking water. Atmospheric lead is also a major source of lead in household dust.

Particulate Matter:
Particulate matter (PM) represents a broad class of chemically and physically diverse substances that exist as discrete particles (liquid droplets or solids) over a wide range of sizes. Particles may be emitted directly to the atmosphere or may be formed by transformations of gaseous emissions such as sulfur dioxide or nitrogen oxides The key health effects associated with PM include premature death; aggravation of respiratory and cardiovascular disease, as indicated by increased hospital admissions and emergency room visits, school absences, work loss days, and restricted activity days; changes in lung function and increased respiratory symptoms; changes to lung tissues and structure; and altered respiratory defense mechanisms. Exposure to coarse fraction particles is primarily associated with the aggravation of respiratory conditions such as asthma. Fine particles are most closely associated with health effects such as premature death or hospital admissions, and for cardiopulmonary diseases.

Unburned hydrocarbon:
Concentrations of unburned hydrocarbons are influenced by air fuel ratio. Lowest emission levels are associated with an air fuel ratio near stoichiometric. Further, highest levels of hydrocarbon emissions are associated with idle and low speed operation. Exceptionally high values of hydrocarbons in the exhaust, usually are indicative of misfiring.

Polycyclic aromatic hydrocarbon (PAH):
PAHs are a group of chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances. PAHs can be man-made or occur naturally. A few of the PAHs are used in medicines and to make dyes, plastics, and pesticides. They are found throughout the environment in the air, water and soil. There are more than 100 different PAH compounds. Although the health effects of the individual PAHs vary, the following 15 PAHs are considered as a group with similar toxicity: acenaphthene, acenaphthylene, anthracene, benzanthracene, benzopyrene, benzofluoranthene, benzoperylene, benzofluoranthene, chrysene dibenzanthracene, fluoranthene, fluorine, indenopyrene, phenanthrene, and pyrene.

Several of the PAHs, including benzanthracene, benzopyrene, benzofluoranthene, benzofluoranthene, chrysene, dibenzanthracene, indenopyrene have caused tumors in laboratory animals when they ate them, when they were applied to their skin and when they breathed them in the air for long periods of time. Reports in humans show that individuals exposed by breathing or skin contact for long periods of time to mixtures of other compounds and PAHs can also develop cancer. Mice fed high levels of benzopyrene during pregnancy had difficulty reproducing and so did their offspring. The offspring from pregnant mice fed benzopyrene also showed other harmful effects, such as birth defects and decreased body weight. Similar effects could occur in humans, but we have no information to show that these effects do occur.

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