AN ABSTRACT OF THE THESIS OF

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Physical geography and topography combined with increasing number of motor vehicles have lead to record breaking air pollution levels in Tehran, the capital city of Iran. The objectives of this study were: 1) to document trends in Tehran, Iran's ambient air quality levels between 1988 and 1993; 2) to compare Tehran's air quality standards with the World Health Organization Standards; and 3) to discuss human health risks that may be associated with air pollution at these levels. Data used in this study were obtained from two sources, Iran's Environmental Protection Agency and the Ministry of Health. Tehran has five automated ambient air monitoring stations operated by Iran's EPA and MH, which are located in areas with heavy traffic. The contaminants monitored in these areas were: sulfur dioxide, nitrogen dioxide, carbon monoxide, total suspended matter, and hydrocarbons. Daily samples were collected to provide 24 hours averages for each pollutant and every three month, mean concentrations were reported to Iran's EPA. Composite samples from all five stations

were stored in a data bank operated by Iran's EPA. The ambient air quality standards set by the WHO were obtained from WHO publications (WHO, 1992). Statistical analysis of the data was carried out using a linear regression model, which was designed to fit the air pollution data and take into account missing data. From the available data it was concluded that there was a statistically significant ($p < 0.00$, 90% CI) upward trend in air pollution levels in Tehran for all the measured pollutants except for NO_2 during the years 1988 to 1993. It was also concluded that WHO guidelines were substantially exceeded by all pollutants except TSM. The data findings suggest that long term exposure to air pollutant levels that exceed WHO guidelines are likely to have come from motor vehicles and industrial sources. As the population growth continues, and increasing number of motor vehicles are driven in Tehran, there is concern for the health effects that may be caused from these pollutants. The results indicated that without a continuous air pollutant monitoring program in Tehran and pollution control strategies, the upward trend is expected to continue which may result in deterioration of the health of Tehran's residents.

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from 1988 to 1993

by

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Mehra A. Shirazi, Author

In the Name of God (Allah), the Most Compassionate the Most Merciful

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
Research Questions	4
Objectives	4
Limitations	5
Definitions	5
LITERATURE REVIEW	8
Major Types of Air Pollutants, Sources and Health Effects	8
Factors Affecting Concentration of Air pollutants	15
The Word Health Organization Standards	25
Air Pollution in Developing Countries	26
Islamic Republic of Iran	30
Role of Motor Vehicles in Tehran's Pollution	38
METHODS	40
Data Collection	40
Statistical Analysis	42
RESULTS	45
Sulfur dioxide (SO_2)	45
Carbon monoxide (CO)	45
Total Suspended Matter (TSM)	47
Nitrogen dioxide (NO_2)	49
Hydrocarbons (HC)	50
DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS	51
Interpretation of Trends	51
Additional Political and Social Factors	57
Conclusions	58
Recommendations	60
BIBLIOGRAPHY	63
APPENDIX: Air Pollution Data from Tehran, Iran from 1988 to 1993	68

LIST OF FIGURES

Figure		Page
1.	Map of Iran	32
2.	Suspended Particulate Matter in Cities of the GEMS Air Monitoring Network, 1976-1980	37
3.	Map of Tehran and Location of the Air Pollutant Monitoring Stations	41
4.	Monthly Mean Ambient SO_2 Levels in Tehran, Iran from 1988 to 1993	46
5.	Monthly Mean Ambient CO Levels in Tehran, Iran from 1988 to 1993	47
6.	Monthly Mean Ambient TSM Levels in Tehran, Iran from 1988 to 1993	48
7.	Monthly Mean Ambient NO_2 Levels in Tehran, Iran from 1988 to 1993	49
8.	Monthly Mean Ambient HC Levels in Tehran, Iran from 1988 to 1993	50

LIST OF TABLES

Table Page

1. Projections in Urban Populations, By Region, 1950-2000....................................19

2. Third World Population, By Region and its Distribution Between Rural Areas and Different Size Urban Centers....................................20

3. World Distributions of Motor Vehicles in 1986....................................22

4. World Health Organization Ambient Air Quality Standards....................................26

5. Observed and Projected Urban Population Data in Iran....................................34

6. Estimated Motorized Trips in Selected Metropolitan Countries....................................39

Air Pollution Trends in Tehran, Iran from 1988 to 1993

INTRODUCTION

The last decade has shown an increase in public and governmental concern about air pollution, and in particular, that generated by man-made processes associated with the life style of modern society. One of the major sources of air pollution is urban areas, with characteristic patterns of pollutant emissions that have adverse consequences to the health of their inhabitants. With the absence of pollution control strategies in many urban areas of the world, the air pollution problem will continue to worsen and result in deterioration of the health and well-being of urban residents (World Health Organization, 1992). Most urban areas have a variety of air pollution sources. The contribution of motor vehicles, industrial sources and domestic emissions to air pollution differs between cities and depends on the level of motorization, population density and industry. In all cases, exposure to air pollution is a problem of increasing concern, as it can adversely affect human health.

Air pollutants are categorized as "primary" and "secondary". Primary air pollutants are emitted directly into the atmosphere from different sources. Examples of primary air pollutants are carbon monoxide (CO), Hydrocarbons (HC), oxides of sulfur (SO_X), oxides of nitrogen (NO_X), and particulate matter such as smoke and dust. Secondary air pollutants are formed in the atmosphere as a result of chemical or physical processes such as hydrolysis, photochemistry and oxidation. They include nitrogen dioxide, photochemical oxidants, and acidic depositions. Secondary air pollutants are responsible for most of the smog, haze, and eye irritation (Stern et al., 1984).

Natural sources of air pollution include volcanoes, forest fires, dust storms, oceans, lakes, and vegetative matter. Anthropogenic sources include industrial sources which are stationary such as power plants and incinerators. Personal sources of air pollution are home furnaces, home fireplaces, stoves and transport. Automobiles are by far the predominant contributor to air pollution among mobile sources (Stern & Boubel, 1984).

Long term exposure to common air pollutants such as sulfur dioxide and carbon monoxide directly affect the respiratory and cardiovascular system (WHO, 1979; Tango, 1994). Recent research has determined that long-term exposure to air pollution causes lung cancer (Tango, 1994). Epidemiological studies have consistently shown an association between particulate air pollution and exacerbation of illness in people with respiratory disease as well as increases in the number of deaths from cardiovascular and respiratory disease among older people (Seaton & Mac Nee, 1995). Overall, the studies from many countries confirm that living in urban, as compared with rural areas, is associated with increased prevalence of respiratory symptoms and sensitization to allergens. These differences could be explained by air pollution (Braback & Dreborg, 1994).

The World Health Organization (WHO) Commission on Health and Environment has identified urban air pollution as a major health problem deserving high priority of action (WHO, 1992). To reduce the effects of exposure to air pollutants, WHO has drawn up air quality guidelines indicating exposure levels below which harmful effects are unlikely to occur. Recent studies show that over the last two decades, air quality in larger cities of the developing world continues to decline (WHO, 1992). Tehran, the capital city of Iran, has been identified by WHO as one of the most polluted cities in the world (WHO, 1992). A booming population increase and even greater growth in vehicle usage make mobile sources responsible for 65% of this pollution (Iran-EPA, 1994). Motor vehicle registration has doubled in six years from one million in 1986 to almost two million in 1992 (Iran-Traffic Dept., 1992). An estimated 12 million motorized trips a day are made in Tehran, which when compared to estimated trips in metropolitan areas of other developing countries is one of the highest rates in the world (Iran-EPA, 1994). The majority of Tehran's anthropogenic pollutants such as carbon monoxide (97%), hydrocarbons (80%), lead (100%) and total suspended matter (9%) are emitted from motor vehicles (Iran-EPA, 1994).

Assessments of air pollution are based on limited data collected by Iran's Environmental Protection Agency. Much of these data are not analyzed in a timely manner, therefore precluding the development of an effective long term air pollution control program. It is hoped that this study will be useful to Iranian officials in the analysis and interpretation of existing data, and also in the planning of efficient air quality monitoring programs for the future of Tehran.

The purpose of this study, therefore, was to determine trends in Tehran, Iran's ambient air quality levels between 1988 and 1993, and to report changes that have occurred during this period that may affect human health.

Research Questions

The following research questions were considered:

1. How have the levels of air pollutants in Tehran, Iran changed during the period from 1988 to 1993?
2. How do the air pollution levels in Tehran, Iran compare to the World Health Organization air pollution standards?
3. Do the levels of air pollution during the years 1988 to 1993 pose potential health risks to the population living there?

Objectives

The three main objectives of this research were:

1. To document air pollution trends in Tehran, Iran from 1988 to 1993 based on existing data.
2. To compare Tehran's air quality data with the World Health Organization's air quality standards.
3. To discuss potential human health risks that may be associated with air pollution at these levels.

Limitations

Iran lacks a comprehensive air monitoring system and resources are not available to monitor all pollutants in a routine manner (Iran-EPA, 1994). Assessments of air pollution were therefore based on this limited data obtained by Iran's EPA and Ministry of Health. Another limitation of this study was the lack of cooperation from Iran's EPA in releasing current information and data on the status of air quality in Tehran. The data-base on ambient air quality status of Tehran and other major Iranian cities was limited to information collected by Iran's EPA. Because these statistics are regarded as politically sensitive they are often not released. If they are published there is usually a considerable time lag between the date of collection and public notification.

Definitions

Acute effects: Immediate health effects due to short term, high level exposure to a harmful substance.

Aldehydes: Organic compounds containing-CHO group produced by partial combustion of fuels. Toxic irritants are chemically reactive in the atmosphere.

Ambient air: Localized outdoor atmosphere.

Anthropogenic: Of human origin.

Chronic effects: Health effects due to long-term exposure to harmful substance at sub-lethal levels.

Emission: Process of discharge into the atmosphere.

EPA: The Environmental Protection Agency in Iran

Epidemiological study: A study of factors affecting the prevalence of disease within a population.

Fossil fuels: Fuels derived from organic deposits in past geological periods, such as coal, oil and natural gas.

GEMS: The Global Environmental Monitoring System sponsored by the United Nations Environmental Program.

Inversion: A weather phenomenon in which cold air lies close to the earth's surface, trapped by a warm air mass above it. This is the inverse of the normal situation in which temperature decreases with increasing distance from earth.

MH: Ministry Of Health in Iran

Mega city: Cities defined with a current or projected population of ten million or greater.

Oxidants: Reactive species, eg. O_3 and NO_2, which add oxygen or extract hydrogen from other materials. Active constituents of photochemical air pollution.

PPM: Parts per million

Photochemical air pollution: Production of secondary pollutants by photochemical reactions in the air, notably oxidants from nitrogen oxides and hydrocarbons.

Primary pollution: Emission of a pollutant directly from the source.

Secondary pollution: Formation of pollutants as a result of the interaction of primary pollutants and other species in the atmosphere.

UN: The United Nations

Urbanization: The change of habitat of humans from primarily rural to mainly cities.

WHO: The World Health Organization

LITERATURE REVIEW

This literature review is divided into four sections. The first section identifies major types of air pollutants, their sources and health effects. The second section examines the main factors that influence the emission, transportation and dispersion of air pollutants in the megacities. The third section reports how the World Health Organization and the United Nations Environment Program address urban air pollution, particularly in the developing world. The fourth section summarizes important geographical, demographic and meteorological data from the Islamic Republic of Iran

Major Types of Air Pollutants, Sources and Health Effects

Long term exposure to the most common air pollutants directly affect the respiratory and cardiovascular system (WHO, 1979; Tango, 1994). According to the Commission on Health and Environment, the extent to which air pollution poses a risk to the general public depends on the health status of the population group exposed, the amount of the pollutant, the hazard of the compound released, the atmospheric conditions leading to the dilution and dispersal of the pollutant, and the period of exposure (WHO, 1992). The most common air pollutants are, carbon monoxide, nitrogen dioxide, sulfur dioxide, total suspended particulate matter, hydrocarbons, ozone and lead.

Carbon Monoxide (CO)

Carbon monoxide is a colorless, odorless, poisonous gas produced by the incomplete burning of carbon, primarily from gasoline-powered motor vehicles. Because transportation sources, especially the automobile are the major source of CO, cities with heavy traffic may have high levels of CO. Other important sources of CO are wood stoves and slash burns (Revelle & Revelle, 1992).

Inhaled carbon monoxide enters the blood stream and binds to hemoglobin (the red pigment in the blood that carries oxygen to the cells). This reduces the oxygen-carrying capacity of the blood and can result in adverse health effects. High concentrations of CO impair the functions of oxygen-dependent tissues, the brain, heart, and muscle (Watson & Bates, 1988; WHO, 1992). In healthy adults, carbon monoxide has been linked to increased heart disease, decreased athletic performance, and diminished mental capacity (Allerd, 1989; WHO, 1992). Individuals with anemia, emphysema, and other lung disease, as well as cigarette smokers are likely to be more susceptible to the effects of carbon monoxide (Allerd, 1989; WHO, 1992). A new study now indicates that even federally permissible levels of CO can aggravate these conditions and that even on days that CO levels fell below EPA's limits, a 20 to 40 percent increase in heart failure admissions for every 10 ppm increase in CO levels was recorded (Raloff, 1995). The Morris study found that between 2 and 11 percent of hospital admissions for congestive heart failure, depending on the city could be traced to CO (Raloff, 1995). CO has also been linked to other health problems. Surveillance of carbon monoxide related morbidity from 1981 to 1991 in Colorado showed 981 cases of unintentional CO poisonings. Most deaths often resulted from fire-related carbon monoxide intoxication (36.2%), followed by motor vehicle exhaust (34.5%), and furnace (10%) (Cook & Simon, 1995). High CO concentrations have also been associated with low birth weight and increased infant mortality (Committee on Automotive Air Pollution (CAAP), 1983).

Nitrogen Dioxide (NO_2)

Nitrogen dioxide is a reddish-brown gas that plays a major role in the production of photochemical oxidants or smog (Revelle & Revelle, 1992). Major sources of NO_2 are fuel combustion in motor vehicles, utility and industrial boilers. Among the Third World cities for which there is data on nitrogen dioxide levels, the highest averages are usually among the cities in the wealthier nations, such as Sao Paulo and Singapore, while cities such as Bombay and New Delhi have relatively low averages (WHO, 1992). Along with sulfur dioxide, NO_2 emissions also are serious contributors to acid deposition. Exposure to nitrogen dioxide emissions is linked to increased susceptibility to respiratory infection such as bronchitis and pneumonia (Beckett & Russi, 1995; Philip, 1995). Short term exposures to NO_2 have been linked to respiratory problems in school children such as coughs, runny noses and sore throats as well as increased sensitivity to urban dust and pollen by asthmatics (Seaton & MacNee, 1995).

Sulfur dioxide (SO_2)

A harsh irritant, sulfur dioxide is a colorless gas, that enters the air primarily from the burning of high sulfur coal. Diesel fuel and heating oil are other sources of SO_2 emissions (Revelle & Revelle, 1992).

When SO_2 is inhaled it causes bronchial constriction resulting in breathing difficulty and increased pulse and respiratory rate. People with existing heart disease and respiratory problems such as asthma, bronchitis, or emphysema are more susceptible to the effects of SO_2 (Toulomi & Pocock, 1994). Studies in Athens from 1975-1982 indicate a positive association of sulfur dioxide with total daily mortality (Toulomi et al., 1994). When sulfur dioxide is oxidized to sulfuric acid (H_2SO_4) the harmful effects of SO_2 increases by a factor of two to three. Inhaled SO_2 increases mucous production, which reduces the respiratory system's ability to remove particulate matter, and can lead to severe respiratory infections such as pneumonia. Long term exposure can lead to coughs, shortness of breath, fatigue, and bronchitis (Watson et al., 1988).

Total Suspended Particulate Matter (TSPM)

TSPM is the general term for particles or liquid droplets small enough to remain suspended in air and less than 100 micrometers in diameter. Some particles are, however, large enough to be seen as smoke. Natural sources of TSPM include pollen and dust. Human caused sources include a variety of combustion sources such as motor vehicles, industrial boilers, wood stoves, field burning and mining (Walsh & Karlson 1990; CAAP, 1983). The WHO is increasingly concerned about suspended particulate matter, particularly because data from Third World cities show increasing levels, with a high proportion of the population exposed to unacceptable concentrations (WHO, 1992).

The health effects of TSPM vary with the size, concentration, and chemical composition of the particles. TSPM irritates mucous membranes and may initiate a variety of respiratory diseases. The particles may be carriers of toxic substances emitted by motor vehicles. For example, analyses of the chemical composition of TSPM from Beijing shows the presence of relatively high levels of organic compounds, including the carcinogen benzo-pyrene (WHO, 1992). A strong correlation exists between suspended particulate and infant mortality in urban areas (Walsh et al., 1990). In Poland increased chronic respiratory symptoms have been linked to high levels of exposure to TSPM in children (Jerdrychowski & Flak, 1995). Estimates suggest that between 300,000 and 700,000 premature deaths a year could be avoided in the Third World if TSPM concentration levels were brought down to those considered safe by WHO (World Bank, 1992).

Hydrocarbons (HC)

Non-methane hydrocarbons are a large family of compounds made up of hydrogen and carbon. These compounds are very important in the series of reactions leading to the formation of ozone and photochemical smog (Simpson, 1995).

Motor vehicles, fuel evaporation and combustion processes are the main sources of these compounds (Revelle & Revelle, 1992). Low-molecular weight HC compounds may cause eye irritation, coughing and sneezing, drowsiness and symptoms similar to drunkenness. Heavy-molecular weight HC have been shown to have carcinogenic or mutagenic effects (Walsh et al., 1989).

Ozone (O_3)

Ozone is formed by chemical reactions that occur between nitrogen oxides and hydrocarbons in the presence of sunlight. Ozone is one of the more serious and common auto-related pollutants, and the main ingredient in urban smog. Exposure to ozone may cause eye irritation, coughs and chest discomfort, headaches, upper respiratory illness, increased asthma attacks, and reduced pulmonary function (Koeing, 1995). The length of exposure, frequency of exposure, and ozone concentration are significant factors in determining the effects. A five year study conducted in central New Jersey showed a 28% increase in emergency hospital visits for asthma problems when ozone levels were less than 0.06 ppm (Weisel & Cody & Lioy, 1995). This supports a proposition that individuals with asthma or diseases of the heart and circulatory system can experience symptoms at ozone concentrations levels below current US standards of 0.06 ppm. (Koeing, 1995; Weisel et al., 1995)

Lead

Leaded gasoline is a primary source of atmospheric lead in urban areas were leaded gasoline is still allowed (WHO, 1992). Air-borne lead particles are normally small in size (less than 0.7 microns), and thus are able to penetrate deep within the lungs and ultimately be absorbed in to the blood. Lead is physically harmful when ingested or inhaled. It accumulates in the body in the blood, in bone and in soft tissues. High concentration of lead in blood can cause severe and permanent brain damage, especially in children. Studies show that children with high levels of lead accumulated in their baby teeth experience more behavioral problems, low IQs, and decreased ability to concentrate (Needleman, 1979; Nikiforov & Bioadzheiva, 1993). Children's exposure to lead is not only from motor vehicles but also from lead water piping, lead in paint and some industrial emissions (WHO, 1992). Neurological impairment, such as seizures, mental retardation, and behavioral disorders have also been linked to lead ingestion (Nikiforov et al., 1993; Rosen, 1995). A study undertaken by the World Health Organization and the United Nations between 1979 and 1981 found the highest lead concentration in Mexico City residents. Ten percent of the sampled population had blood lead concentrations well above the WHO guidelines, at a level which biochemical changes begin to occur (WHO, 1992). A more recent study in Mexico City in 1988 found that a quarter of the newborn infants in Mexico City had lead levels in their blood high enough to impair neurological and motor-physical development (World Resources, 1993). Lower levels of exposure have non-specific symptoms, such as headaches, stomach pain and irritability and eye irritation (WHO, 1992).

Factors Affecting Concentration of Air Pollutants

The extent to which particular pollutants or a mixture of pollutants impose a threat to human health in the megacities depend on the following factors: meteorology, weather conditions, demography, economic development, urban growth and motor vehicles.

Meteorological factors that affect the dilution and transformation of the air pollutants are wind speed, wind direction, atmospheric stability, amount of sunlight or intensity of solar radiation, precipitation and temperature (Bellomo & Liff, 1984; Eagleman, 1991). These factors influence hourly, daily and seasonal concentrations of emitted pollutants. Inversions more often occur during cold nights when a layer of colder air is trapped beneath a layer of warmer air so that the normal vertical temperature profile is reversed. Pollutants collect in the cold air, and as the sun warms the lower air, vertical thermal currents are set into motion to warm the cold layer. The currents however, might not reach the upper air. This will increase the concentration of contaminants through the day because little pollution escapes. The level of contaminants becomes increasingly dangerous if condition persists several days in a row (Revelle & Revelle, 1992).

Atmosphere patterns can increase or decrease pollutant concentrations. A stable atmosphere will increase pollutant concentrations while an unstable atmosphere tends to minimize pollutant concentrations. Stability of the atmosphere is related to temperature structure, variation in wind speed and its direction with height (Bellomo & Liff, 1984; Eagleman, 1991). For instance in cities such as Bangkok and Buenos Aires, the location on or close to the coast on a flat plain means that a prevailing wind helps disperse pollutants. For cities in valleys (such as Mexico City and Tehran) or surrounded by mountains particular weather conditions help trap pollutants for substantial parts of the year (WHO, 1992).

The United Nations estimates that by the year 2000, 47 percent of the world's population will be living in urban areas (United Nations Environmental Program, 1990). In 1990, 69 cities had populations of 3 million or more, and by 2000, 85 cities will probably be this size or larger (UNEP, 1990). As the populations of urban areas increase, the number of people exposed to urban air pollution is likely to increase (WHO, 1992).

Other factors directly influence air pollution trends. For example, economic policies, along with trade and sectoral policies, influence the use and degradation of natural resources, affect health through the level of government expenditure on health services, sanitation, education and poverty relief (Brown, 1995; WHO, 1992). Today most parts of the Third World are facing a severe economic and social crisis. Although more countries are pursuing a policy of rapid industrialization, their economies are stimulating increasing demand for nonessential goods and services (Brown, 1995). In many countries, the combination of low export prices and unsuitable projects has led to a crisis in debt servicing. The external debt of developing countries has grown more than 7 percent to an estimated $1.9 trillion since 1993 (Brown, 1995). Many Third World countries expand the volume of their commodity exports to service their foreign loans, which increases the volume of raw materials exported from Third World countries. This kind of industrial development and economic growth is associated with increased energy consumption which can produce deterioration of environmental quality and conditions that are potentially damaging to human life (WHO, 1992). In 1994, the Iranian Environmental Report reported that the magnitude of economic activity strongly influences the degree of urbanization (Iran International Relations, 1994). This report shows that almost all Third World governments have failed to ensure that rapid urban growth is accompanied by the investment needed in the infrastructure and services, especially in residential areas with a predominance of poorer households (IIR, 1994).

Urban population growth in developing countries arising from natural increases and migration from rural areas has resulted in increased travel and demand for urban transport services. By 2050, the UN projects, global population will rise to 7.9 billion (Brown, 1995). Cities in developing countries are facing rapid population growth, as urban populations in developing countries more than doubled from 17 to 37 percent between 1950 and 1995 (Brown, 1995). It is predicted that by the year 2025, 60 percent of the world's population will live in the urban areas, and Latin America will have the highest percentage of urban population (Brown, 1995). UN projections suggest that the Third World urban population will grow by more than 700 million persons between 1990 and 2000, in contrast, the growth in the urban population in the rest of the world is projected at a little more than 70 million (See Table 1).

The major causes of urban growth are internal population growth, rural to urban migration, and the extension of urban boundary areas (Brown, 1995). One outcome of this rapid growth in the Third World's urban population has been an increase in the number of large cities. In 1950 there were just ten cities with more than one million people and in 1990 there were 171 urban centers (WHO, 1992). Michael Cohen, chief of the Bank's urban development division, points out that "spatial expansion" degrades the environment, and has sharply raised the cost of communication, transportation, and economic exchange in the world's megacities. These problems are worse in developing countries due to poorly developed infrastructures, mainly in communications. Cohen believes that rapid urban growth therefore, may have an indirect link to increased pollutant emissions, and the air pollution problem is sure to intensify with increased urbanization in developing countries. 300-400 million persons will be exposed to unhealthy levels of air pollution by the year 2000 (WHO, 1992). Most of the Third World urban population now live in urban centers with fewer than half a million inhabitants and less than 3 percent of the Third World population live in "megacities" of ten or more million inhabitants (See Table 2).

Table 1. Projections in Urban Populations, By Region, 1950-2000.

Region	1950	1970	1990	2000
Urban population (millions of inhabitants)				
Africa	32.3	82.7	217.4	352.4
Latin America & Caribbean `	68.8	163.6	320.5	411.3
Asia (not incl. Japan)	184.4	406.8	975.3	1,485.7
Other	0.2	0.7	1.4	2.1
Third World total	285.6	653.8	1,514.7	2,251.4
Rest of the world	448.2	698.6	875.5	946.2
Percentage of population living in urban centers				
Africa	14.5	22.9	33.9	40.7
Latin America & Caribbean	41.5	57.3	71.5	76.4
Asia (not incl. Japan)	14.2	20.4	32.6	41.5
Other	7.5	17.5	23.1	27.3
Third World total	17.0	24.7	37.1	45.1
Rest of the world	53.8	66.6	72.6	74.9

Source: The United Nations Environmental Program Data Report, (1992).

Megacities can only exist if there is an economy which can provide incomes for a population concentration of this size. The majority of the Third World nations are never likely to have the population or the economic base to allow the development of a megacity (World Bank, 1994). The World Bank's report suggests that environmental problems in many of the Third World countries are rarely the result of an overall shortage of space within the city, but are much more the result of the concentration of a high proportion of the city's poorer population in a very small area (World Bank, 1994). For example, a study of environmental problems in Nairobi highlights that the very high population densities in illegal and informal settlements house a substantial proportion of the city's population. Shanghai and Colombo are among the many Asian cities that have generally low population densities, but very high population densities in central districts and other specific areas (World Bank, 1994).

Table 2. Third World Population, By Region, for 1990 and its Distribution Between Rural Areas and Different Size Urban Centers.

Population (in millions)	**Third World**	**Latin America**	**Asia**	**Africa**
Total population (million)	4,086	448	2,989	642
Urban population	1,515	320	975	217
Rural population	2,571	128	2,014	425
Proportion of total population living in rural and urban areas (%)				
Rural areas	62.9	28.5	67.4	66.1
Urban areas with less than 1 million	24.6	41.8	22.0	24.7
Urban areas with 1-2 million	3.2	5.6	2.8	3.4
Urban areas with 2-5 million	3.8	9.4	3.1	3.1
Urban areas with 5-10 million	2.6	1.4	2.7	2.6
Urban areas with 10 million plus	2.4	8.8	1.9	0.0

Source: The United Nations Environmental Program Data Report, (1992)

The Organization for Economic Cooperation and Development (OECD) has been giving attention to the problems of transportation and environment in several ways since 1974. A set of papers that were written for OECD organized the data on transport related environmental problems and the options for policy response. Wilfred Owen writes about the developing countries (1979). These countries present different problems than do developed countries in that they appear to be less responsive in reversing environmental problems but, at the same time, are seeing increasing population and automobile use. Owen (1979) believes that the most effective immediate answer to automobile congestion would be a concentrated effort to improve public transportation. He writes, “the importance of a combined strategy for transportation and urban development stems not only from the critical problems of the moment but from population projections that assume nearly a thousand million more people in the cities of developing countries between now and the year 2000” (Owen, p. 296). Although it might be assumed that air pollution from motor vehicles is a lesser problem in poorer nations because they have fewer cars as compared to Europe, North America, or Japan, this is not accurate. Major cities in more wealthy Third World nations have as many automobiles per capita as many cities in developed countries (Brown, 1995).

1973 data on world motor vehicle registration shows an upward trend in registration of private cars which increases as the national income rises. For example, the number of motor vehicles increased 35 percent in US in the 1960s ,100 percent in South America, and 300 percent in Asia. The number of vehicles increased 500 percent in Thailand and 300 percent in Pakistan and the Philippines (World Bank, 1989). The world distribution of the motor vehicle population in 1986 is shown in Table 3.

Table 3. World Distribution of Motor Vehicles in 1986.

Region	Automobile(%)	Trucks & Buses (%)
North America	40.0	41.4
Europe	39.8	21.0
Asia	11.1	27.8
South America	4.8	3.7
Oceanic	2.2	2.3
Africa	2.1	3.7

Source: Motor Vehicles Manufacturers Association, (1988)

North America and Europe each had 40% of the world's automobile population in 1986. Asia, South America, Oceanic and Africa accounted for the other 20%. North America also accounted for 41% of the trucks and buses, Europe 21%, and Asia 27%. In Asia, Japan had 70% of automobiles and 62% of trucks and buses. The developing countries had 10% of the world's automobiles and about 20% of trucks and buses (Motor Vehicles Manufacturers Association, 1989). When the world auto production rose in 1994 the United States recorded a 15% growth in production, and Western Europe showed a 3.5% increase. Brazil's auto production increased 40% in two years from 1992 to 1994, reaching 1.5 million (Brown, 1995). A greater increase (18%) in auto production occurred in Asia and the Pacific region (excluding Japan), with China's production rate skyrocketing at 28% in a year (Brown, 1995). Many developing nations are encouraging foreign auto production with the hope that it will create jobs and stimulate the economy. The impact of motor vehicle increase in the developing world is magnified by the fact that automobiles are heavily concentrated in a number of large metropolitan centers and third world cities are coping with motorization with far less road way capacity, poorly maintained vehicles, and generally no subways. With urban growth and the anticipated increase in automobile ownership, motor vehicle air pollution in many large cities in the developing world will be much worse than the projected levels for major cities in industrialized countries (WHO, 1992).

Common modes of land transport in developing countries are: automobiles and taxis, motorcycles, vans, pickups, light and heavy duty trucks, buses and minibuses, trolley buses and trams, trains and, non-motorized modes (human and animal drawn vehicles, bicycles, and walking) (World Bank, 1994). Whether or not a vehicle contributes to pollution depends on the condition of the engine, the fuel, the operating conditions (speed, traffic congestion) and physical conditions. In many developing countries motor vehicles are not as fuel efficient as in industrialized countries. Vehicles tend to be old and poorly maintained due to insufficient garage equipment and lack of spare parts as well as lack of trained mechanics. For example most motor vehicles in India and Mexico City are more than ten years old (Pendakur, 1988).

Motor vehicles are responsible for over 90% of CO, 40% of NOx and 90% of lead emissions in urban areas (WHO, 1992). In many large cities in the Third World, emissions from motor vehicles and the secondary pollutants (such as ozone) to which they contribute, are more of a problem than the traditional pollutants from coal and heavy oil combustion, which are the main problem in smaller and poorer cities (WHO, 1992). A more common indicator of the health impact of air pollution from motor vehicles comes from the comparisons between the health of people in highly polluted areas with a high concentration of motor vehicles against those in less polluted areas. For instance a recent study on the short-term effects of mortality in Athens suggests that current air pollution levels of smoke and CO are responsible for substantial numbers of premature deaths (Toulomi, 1995). In cities where acute air pollution episodes occur at particular times, the link between air pollution and health is documented in increased mortality among vulnerable groups, such as the elderly (WHO, 1992).

Motor vehicles are a significant source of toxic compounds that according to US EPA, may be responsible for 1,874 cancer cases per year in the United States (Carhart & Walsh, 1987).

Diesel Particulates

Diesel particles are of environmental and health concern because most of these particles are small and restorable (less than 2.5 microns). Diesel particles may cause cancer and increase mortality and morbidity from respiratory disease (Carhart & Walsh, 1984; Muscat & Wynder, 1995). A study by the Swedish National Institute of Environmental Medicine showed a significant association between exposure to diesel exhaust and lung cancer among truck drivers. The study indicated a 30 to 50% increase in risk of lung cancer among these drivers (CAAP, 1983). A more recent study concluded that short term exposure to diesel engine exhaust may not have a causative role in human lung cancer, however, there was evidence that could link long term exposure to diesel exhaust with lung cancer in diesel engine mechanics and drivers (Muscat et al., 1995). Diesel engines can emit up to 100 times more particles than the gasoline engine (Carhat & Walsh, 1987; Lewats, 1981)

Asbestos

Asbestos is used in brake linings, automatic transmissions and clutches (Jaffrey & Rood &Scott, 1992). Studies have shown that brakes containing asbestos released airborne particles under abrasion (Jaffrey & Rood, 1992). In 1984, 22% of the asbestos consumption was used in United States for motor vehicles. Health effects of asbestos are cancer, asbestosis (a condition that results from long term exposure to asbestos), and mesothelioma (Carhart & Walsh, 1987).

The World Health Organization Standards

One of the activities of the World Health Organization involves the improvement and establishment of air quality monitoring stations around the world. The WHO established a global program of air quality monitoring in 1973.

Assessment of air quality consists of examining the existing air quality in a particular region and comparing this to established air quality standards (WHO, 1976; WHO, 1992). The WHO has set such standards since 1975 to protect the public health and welfare from the known adverse effects of air pollution (WHO, 1976). Many countries set their own national air quality standards that may be legally enforced. For example, in the United States there are two sets of air quality standards: primary and secondary. Primary standards define levels of air quality that protect the public health and take into account sensitive populations such as children and the elderly. Secondary standards protect public welfare including: soil, water, crops, vegetation, animals, property damage, effects on economic values and personal well-being (Cohn & McVoy, 1982). The ambient air quality standards set by the World Health Organization are summarized in Table 4.

Table 4. World Health Organization Ambient Air Quality Standards.

Pollutant	**Standard**	**Averaging Time**
Sulfur dioxide (SO_2)	100-150 $\mu g/m^3$ (0.038-0.052 ppm)	24 hrs
Carbon monoxide (CO)	40-60 $\mu g/m^3$ (0.014-0.0231 ppm)	Annual mean
Nitrogen dioxide (NO_2)	150 $\mu g/m^3$ (0.052 ppm)	24 hrs
Hydrocarbons (HC)	0.24 ppm	3 hrs
Total Suspended Matter (TSM)	150-230 $\mu g/m^3$	24 hrs

Source: World Health Organization, (1992)

Air Pollution In Developing Countries

Although there has been some progress in controlling air pollution in industrialized countries over the last two decades, air quality in developing countries continues to decline (WHO, 1992). For example, between 1973 and 1987 in the United States sulfur oxides emissions were cut by 28 percent and suspended particles decreased by 62 percent. In Japan, sulfur dioxide emissions fell by 39 percent from 1973 to 1984, but New Delhi experienced a 20 percent increase in sulfur dioxide concentration levels during the same period(United Nations Environmental Program, 1988). In 1988, the United Nations Environmental Program (UNEP) and the World Health Organization (WHO) reported on the level of sulfur dioxide pollution. From 1980 to 1984, 27 cities were on the borderline or in violation of WHO health standards (UNEP, 1988). Kuala Lumpur was reported as having a concentration of suspended particulate in the air 29 times the desirable goal recommended by the Malaysian Environmental Quality Standards (UNEP, 1988). Bangkok, Beijing, Calcutta, Delhi, and Tehran were also reported to greatly exceed the WHO seven day guideline (the concentration which should not be exceeded for more than seven-days each year). These cities exceeded this guideline on more than 200 days over the four year period (UNEP, 1988).

A more recent UNEP and WHO study on air pollution in 20 countries of the world's megacities shows a massive deterioration in air quality in the developing world (WHO, 1992). The study examined six major pollutants: sulfur dioxide (mainly emitted from industrial plants), lead, carbon monoxide and nitrogen dioxide (mostly from petrol fumes of cars), and ozone (from the reaction of sunlight on the smog emitted from the vehicles). In order to assess the air quality situation in these 20 cities, information on pollutant sources and emissions were also examined. The study concluded that at least one WHO health guideline was exceeded in all 20 cities (WHO, 1992). Fourteen cities had two pollutants and seven cities had three or more pollutants where concentrations exceeded the guidelines (WHO, 1992). The study indicates that high TSM concentrations are the most prevalent form of pollution. High TSM concentrations were influenced by different factors such as the large amount of natural dust, erosion products and combustion of coal. For SO_2, the upward trend has fortunately reversed in Sao Paulo and nine other cities (WHO, 1992).

High concentrations of carbon monoxide were highly correlated with the number of motor vehicles. For example, despite the existing emission controls in Los .Angeles, CO levels were still high due to increasing number of motor vehicles. In Mexico City the high altitude favors the formation of CO in the internal combustion engine (WHO, 1992). The study points out that motor vehicle traffic is a significant source of air pollution in all of the megacities In nearly half of the megacities, it is the single most important source (WHO, 1992). The WHO (1992) study states, "the contribution of motor vehicles to the pollution is thus set to increase in developing countries in the absence of the introduction of stringent control measures for traffic-related pollutant. It is expected that air quality will deteriorate in these regions." (WHO, 1992, P.9).

Motor vehicles in many developing countries are old and poorly maintained and the gasoline used has a high percentage of lead (Pendakur, 1988). The lack of adequate pollution control technologies and regulations, plus plans to expand energy and industrial production, translate into worsening air quality in many cities. The characteristics and scale of the air pollution problem in most of the developing countries are, however, not known, nor has the problem been researched and evaluated to the same extent as in industrialized countries. Reliable data has been increasingly recognized as an important component of air pollution control strategies. In many developing countries the data on the pollutants and their health and environmental impacts are often non existent, incomplete, or out of date. Another reason for the failure of many environmental initiatives is that the programs and policies of the major international financing and aid organizations continue to be heavily guided by researchers from developed countries. This underrepresentation of research generated in developing countries reflects the biases of the international institutions (International Development Research Center (IDRC), 1992). The WHO report concludes that the future looks worse for many cities of the developing countries mostly because there is little awareness of the severity of the problem. The report warns that few moves have been taken to control the problem in these megacities. UNEP and WHO believe that, by studying past and present air pollution problems and air quality management strategies megacities may be able to avoid repeating mistakes of the past (WHO, 1992).

Perhaps the least surprising point arising from the review of environmental problems in the world is that it is the poorer groups who pay the highest price and bear the ill-health. They are not able to afford good quality housing in neighborhoods with clean air, piped water and adequate provision for piped water (IDRC, 1992). For example, in Mexico City and Tehran, the highest concentrations of TSM in the air were found in the south areas, which are predominately low-income (UNEP, 1987). In Jakarta, Indonesia estimates suggest an infant mortality rate for the whole city at 33 per 1000 live births while estimates for some of the poorer areas suggest four to five times the city average. An estimated 574,000 people with low-incomes live in illegal settlements on slopes with a significant risk of landslides in the city of Caracas (WHO, 1992). In many third world countries various political and institutional factors inhibit environmental action making industrial expansion government's most serious concern. Therefore, pressing problems with debt payment , increasing exports and creating jobs are regarded as high priority which inhibits any long term environmental plans (IDRC, 1992).

Islamic Republic of Iran

Located in southwestern Asia, Iran is an arid land neighboring Armenia, Azerbaijan, the Caspian Sea, and Turkemenistan to the north. The Persian Gulf and the Gulf of Oman are located to the south, Iraq and Turkey border on the west, and Afghanistan and Pakistan are to the east. Iran's total area is 636,294 sq.miles (See Fig 1). Most of the country is elevated above 1,500 feet, and one sixth of Iran is over 6,500 feet. Iran's terrain is distinguished by the Elburz and Zagros mountain chains and by the extensive interior deserts. The Zagros range stretches from the Armenian border in the northwest to the Persian Gulf. It is drained on the west by streams that cut deep , narrow gorges and water fertile valleys. The land is extremely rugged, difficult to access, and populated by nomads. The Elburz mountain chain runs along the south shore of the Caspian Sea. The highest of its mountains are replaced by barren sand dunes (Iran International Relations (IIR), 1994).

Approximately one-sixth of the total area of Iran is barren desert. Most of the desert remains unexplored, since its crust is formed by large sharp edged salt masses overlying mud. Iran's climate ranges from subtropical to subpolar (Iran Today, 1994). Average temperatures vary from a high of 123 degrees F at the head of the Persian Gulf to a low of 35 degrees F in the northwest. Precipitation varies from 78 inches in the Caspian region to 2 inches in the southeast (Iran-Dept. of Statistics, 1995).

Iran is a multi-lingual and diverse cultural society. The official language is Farsi, and many other dialects are spoken around the country. Iran is the third largest oil producing country in the world. Iran is also endowed with natural gas, mineral deposits such as zinc, chromium, copper, sulfur, and iron ore. Its industries include petroleum production, oil refining, textiles, production of cement and other building materials, food processing, and metal fabricating (Iran-Dept. of Statistics, 1991).

Major Environmental Problems

Iran's arid climate , fragile soil and high population growth, combined with the destruction caused by the eight-year war with Iraq and the lack of management of many natural resources, has contributed to critical environmental degradation . Iran's major environmental problems are categorized as the following:

Water Pollution

The Persian Gulf with its highly saline water and narrow bottle-neck at the Strait of Hormus, has been plagued by pollution from heavy oil tanker traffic and a massive oil

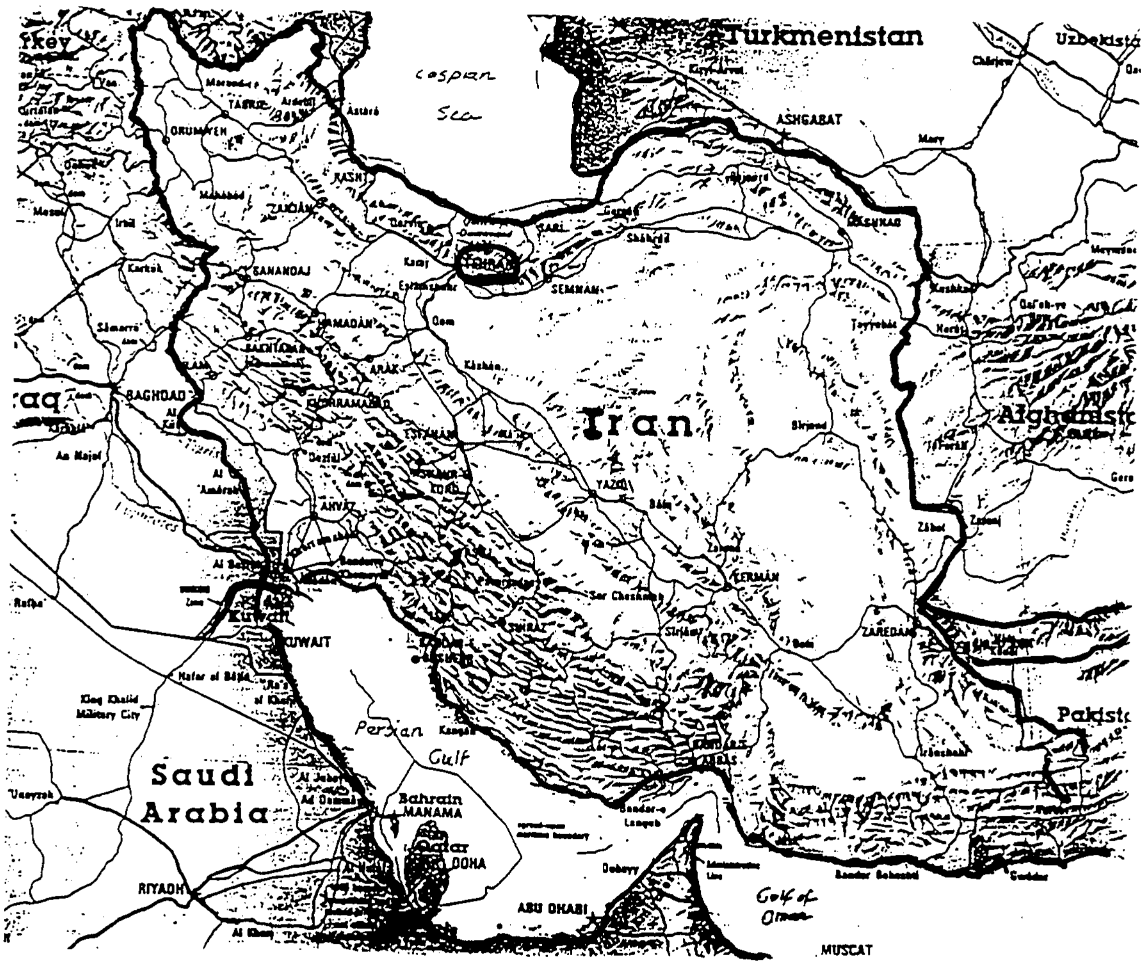

Figure 1. Map of Iran.
Source: Iran Today, (1994)

spill during the 1991 Persian Gulf war. Debris from tanker accidents and downed airplanes, as well as black rain and toxic fumes from burning oil wells in Kuwait, have made this body of water one of the most polluted in the world The water pollution has been threatening the marine food chain and the fisheries on which many Iranians depend for protein (Iran-EPA, 1993).

Water Shortage

Many regions of the country are experiencing drought, with rain fall in recent years well below average. About 87% of the water supply is used in agriculture, 9.0% for industries, and 4.0% in homes and cities. Almost 100% of the urban population and 75% of the rural population have access to safe drinking water. The drought, together with inefficient use of water resources, has created shortages of drinking water for many regions (Iran-EPA, 1994).

High Population Growth

In 1994, Iran's population was 64,525,000. With a total of 3,000,000 refugees from Afghanistan and Iraq, Iran is ranked as the 15th most populous country in the world (World Bank, 1994). With the growth rate of 3.7% and a doubling time of 19.86 years, it is estimated that by the year 2020 Iran's population will reach 113,550,000 (See Table 5).

Life expectancy at birth is 65.2 (years), with 45.9% of the population under 15 and 3.5% over 65 years. Infant mortality rate is 52 per 1000 live births (IIR, 1994).

Table 5. Observed and Projected Population Data in Iran.

Year	Mid-Year Population (thousands)	Urban Population (percent)
1950	14206	27.7
1955	17061	30.6
1960	20301	33.6
1965	24078	36.8
1970	28397	41.0
1975	33344	45.7
1980	38900	49.1
1985	47624	51.9
1990	56585	54.9
1995	64525	58.0
2000	74460	61.1
2005	84646	64.1
2010	94691	67.1
2015	104342	69.8
2020	113550	72.3

Source: United Nations Environmental Program Data Report, (1992)

Air Pollution

Iran's urban air is heavily polluted from motor vehicles, industry, and refinery operations. Motor vehicles are the largest contributors to the problem (Iran-EPA, 1994). According to the International Road Federation, the number of motor vehicles was 17.0 per persons in 1970. In 1991 the number of motor vehicles rose to 39 per person. This number continues to rise which has resulted in a corresponding rise in the level of air pollutants in the last decade (Hamshahrie, 1994). Air polluting industrial enterprises that operate around the country also include power plants, chemical plants, non-ferrous metal smelters, metal products, furnaces, boilers and more traditional air pollution sources such as public baths, bakeries and concrete plants. Oil industry's refinery activities and the methods of distribution and reformation of fuels is responsible for pollution in many parts of the country (Iran-EPA, 1994).

Tehran

Tehran, the capital city of Iran is located in the north-central part of Iran at an altitude of 4002 feet above sea level. The basin is surrounded by the Elburz mountains. Tehran's total area is 10,939 square miles. Although the total population according to 1990 census was 7.0 million almost all international literature suggests a population of 10 to 13 million. This makes Tehran the second most populous city in the Middle East (IIR, 1994).

Tehran has cold winters. The mean monthly temperature for January is 24 degrees F. Summers are hot and dry. The mean monthly temperature for July is 90 degrees F. A maximum hourly temperature of 124 degrees F has also been recorded (Iran Dept. of Statistics, 1995).

Air Pollution Problems

Physical geography and topography contribute significantly to the high concentration of pollutants in Tehran. Tehran's poor atmospheric ventilation, frequent sunshine, and surrounding mountains, combined with extreme temperatures produce ideal conditions that have lead to record breaking air pollution levels that exceed WHO standards (Hamshahrie,1994; Iran-EPA, 1993).

During the period from 1976-1980 several countries participated in a global air monitoring program established by the World Health Organization (WHO, 1980). Daily measurements of sulfur dioxide, suspended particulate matter and smoke were taken by a number of well accepted methods. The comparison of TSM levels for 1976-1980 period is shown in Figure 2. The composite averages range from 59 $\mu g/m^3$ in Tokyo to 142 $\mu g/m^3$ in Zagreb. Unusually high concentrations above 300 $\mu g/m^3$ are obtained for Tehran and Calcutta.

Measurements of smoke and sulfur dioxide in seven cities during 1976-1980 also indicated that over 40% of the sites were above the WHO guidelines for TSM (150-230 $\mu g/m^3$), SO_2 (100-150 $\mu g/m^3$), and smoke (100-150 $\mu g/m^3$).

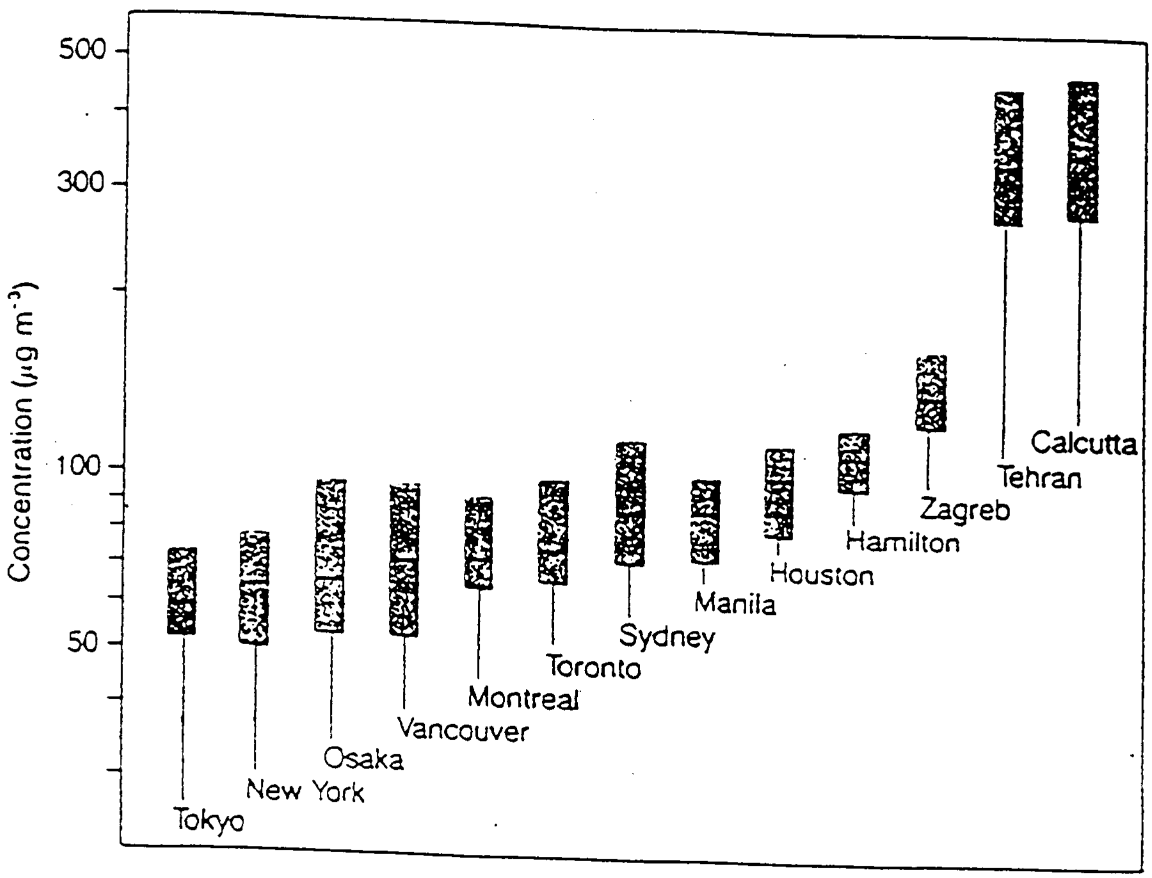

Figure 2. Total Suspended Matter in Cities of the GEMS Air Monitoring Network, 1976-1980.
Source: United Nations Environmental Program, (1987)

After the results of the air monitoring program were published in 1980 Tehran was indicated by WHO as one of the most polluted cities in the world(WHO, 1983).

Role of Motor Vehicles in Tehran's Pollution

Motor vehicles are the primary source of air pollution in Tehran (Iran-EPA, 1994). About 2 million motor vehicles account for 65% of Tehran's air pollution. The number of motor vehicles in Tehran has doubled from 1 million in 1986 to almost 2 million in 1992 (Iran Traffic Department, 1992). The average automobile is ten years old, few have functioning emission controls and at least 65% are reportedly in poor condition (Hamshahrie, 1994). Common modes of transport are buses, minibuses, taxis, trucks, and vans (Iran Traffic Department, 1992). About 20,000 taxis, 10,000 pick up trucks, 3000 buses, and 500 trucks provide daily service in Tehran. Motor vehicles make about 12 million motorized trips per day and only 4.5 million trips per day belongs to public transportation (taxis and buses). It is estimated the number of motorized trips in Tehran will increase from 12 million trips in 1994 to 21.5 million trips per day by the year 2000 (UNEP, 1992). With its high growth rate, Tehran has one of the highest estimated trips when compared to selected areas in other developing countries shown in Table 6. Mobile sources use 4 million liters of gasoline per day which contributes to a vast majority of anthropogenic emissions. About 2000 tons of CO, 382 tons of HC, 86 tons of NO_2, 11 tons of TSM, and 12 tons of SO_2 is emitted daily into the air from these vehicles. These emissions correspond to 97% of the total CO, 80% of the total HC, 9%

of the total TSM and 100% of the total lead emitted into Tehran's air (Hamshahrie, 1994). Emissions are compounded by traffic jammed into narrow and angling streets that reduce the mean rate of travel to 12 kilometers an hour. On-street and road side parking due to limited parking space forces low speed cruising that prolongs the peak traffic period (Iran Traffic Department, 1992). There is no data on emission characteristics of different types of motor vehicles.

Table 6. Estimated Motorized Trips in Selected Metropolitan Areas in Developing Countries

City	Motorized Trips per day (in millions)	
	1980	2000
Bangkok	4.50	11.52
Bombay	5.25	17.69
Calcutta	10.13	18.30
Jakarta	3.38	14.48
Seoul	11.63	15.09
Mexico City	19.88	29.98
Rio de Janeiro	9.78	14.50
Sao Paulo	14.25	26.98
Cairo	3.88	12.01
Tehran	9.65	21.50
Nairobi	0.56	2.79

Source: United Nations Environmental Program Data Report, (1992)

METHODS

The purpose of this study was to determine trends in Tehran's ambient air quality levels between 1988 and 1993, and to report changes that have occurred during this period that may affect human health.

Data Collection

Data used in this study were from two sources, Iran's Environmental Protection Agency (EPA) and the Ministry of Health (MH). Tehran has five automated ambient air monitoring stations operated by Iran's EPA and MH, which are located in areas with heavy traffic. These areas include: commercial areas in west Tehran(Azadi square)and central Tehran(Rahahan square) Tehran with prolonged daily peak-traffic periods and, high density residential areas in north Tehran(Tajrish) and south Tehran(Imam Blvd.) (See Figure 3). The contaminants monitored in these areas were: sulfur dioxide, nitrogen dioxide, carbon monoxide, total suspended particulate matter, and hydrocarbons. Daily samples were collected to provide 24 hour averages for each pollutant and every three months, monthly mean concentrations for each pollutant were reported to Iran's EPA. Composite samples from all five stations were stored in a data bank operated by Iran's EPA. Missing data showed that data was not collected continuously on monthly bases from 1988 to 1993. The ambient air quality standards set by the World Health Organization were obtained from WHO publications (WHO, 1992).

Figure 3. Map of Tehran and Location of the Air Pollutant Monitoring Station.
Source: Iran Today, (1994)

Data on sulfur dioxide and total suspended particulate matter were originally collected by the Ministry of Health as part of the Global Environment Monitoring System (GEMS) which began collecting data in 1977. A complete description of air sampling methods is, therefore, available for these two pollutants. The method employed for the measurement of sulfur dioxide is the Acidimetric Titration Method, in which air is bubbled through a 0.5% hydrogen peroxide solution adjusted to pH 4.5 (WHO, 1992). Any sulfur dioxide present forms sulfuric acid, which is titrated against standard alkali. Assuming that sulfuric acid is the only acid present, the concentration of sulfur dioxide in the air can be calculated. Total suspended particulate matter is measured using the High-volume Sampler Method (WHO, 1992). Samples are collected with high volume samplers which operate similar to a vacuum cleaner. Air is drawn through the filter for 24 hours (midnight to midnight). The sample filter is first weighed before the sampling and reweighed afterwards. The sample weight is expressed as micrograms of particulate per cubic meter of air sampled (Iran-EPA, 1991 ; WHO, 1992).

Statistical Analysis

Statistical analysis of the data was carried out using the following linear regression model to show trends in Tehran's ambient air quality levels from 1988 to 1993.

This equation was designed to fit the air pollution data and take into account missing data:

$$\text{Concentration} = \beta_\circ + \beta_1 \sin(\omega t) + \beta_2 \cos(\omega t) + \sum_{i=1}^{k} \beta_{i+2} \frac{t^i}{i!}$$

where: ω = angular velocity associated with a period of one year.

K = degree of polynomial (1, 2, 3)

t = time in months.

β = constant

β_1, β_2= regression coefficients , $\sum_{i=1}^{k} \beta$ = power term

These models are fit to account for the seasonability in time series as well as any overall trend In this model the pollutant (concentration) was the dependent variable and time(t) the independent variable. The alternative hypothesis states that a trend does exist. Many time series exhibit a cyclical pattern that has the tendency to repeat itself over a certain fixed period of time. The term $\beta_\circ + \beta_1 \sin(\omega t) + \beta_2 \cos(\omega t)$ models the natural up and downs that occur for a pollutant within a year. This is sometimes called the trigonometric term (Abraham et al., 1983). The term $\sum_{i=1}^{k} \beta$, is a power series term, or the power term. The power term tries to account for all the rest of the effect that time has on concentration after accounting for the seasonal effects (Abraham, 1983). The notion in using this equation was made by two assumptions. First, there is an annual cycle imposed on a trend that could be represented by a low degree polynomial. The degree chosen was that which fit the data with the smallest standard error of the estimate. Second, it was assumed that the trend could be described with a linear, quadratic, and cubic regression model.

An examination of the residuals indicated that the variance was not constant requiring a transformation of the response variable (concentration). The square root transformation is often effective in stabilizing the variance of the response variable (Snedecor et al., 1989). This transformation did tend to stabilize the variance. The graphs were made by estimating the mean and the 90% confidence intervals (10% standard error of estimate would count for missing data) and "back transforming" the projections (by taking the response variable to the power of two).

RESULTS

Sulfur dioxide (SO_2)

The monthly mean sulfur dioxide(SO_2) levels from 1988 to 1993 are shown in Figure 4. SO_2 emissions fluctuate with a range from 0.07-0.78 ppm. The graph shows higher SO_2 concentrations in the earlier years, tapering off to lowest levels from 1989 to 1990. Despite a decrease in mean SO_2 levels in 1989 and 1990 the graph shows steadily increasing levels from 1990 to 1993. Regression analysis indicated a significant trend ($p = 0.009$, 90%CI). SO_2 levels seemed to have increased during winter which is indicated at months January and February and lower concentrations occurred during August and September. Extremely high outliers were observed in January of 1989 and March of 1989 and 1991. Ambient SO_2 levels exceeded the World Health Organization guidelines of 0.038-0.052 ppm throughout this period. Highest levels of SO_2 were 15 times greater than the WHO guidelines.

Carbon monoxide(CO)

Carbon monoxide(CO) emissions range from 1.100-23.02 ppm The trend in mean CO levels appears to have demonstrate two patterns: a downward trend leading to a stationary position in 1989 and 1990, followed by an upward trend from 1991 to 1993 (See Figure 4). Regression analysis indicated a significant trend ($p=0.000$, 90% CI). Maximum concentrations occurred mostly in summer, which is indicated at months, June, July and August. Lower concentrations occurred during months of December, January and February. The graph shows extremely high outliers in March of 1988 and October and November of 1993. The reported measurements from October 1988 to April 1991 were below WHO guidelines, however the rest of the measurements exceeded WHO guidelines of 0.14-0.023 ppm. Highest levels of CO were 1000 times greater than the WHO guidelines.

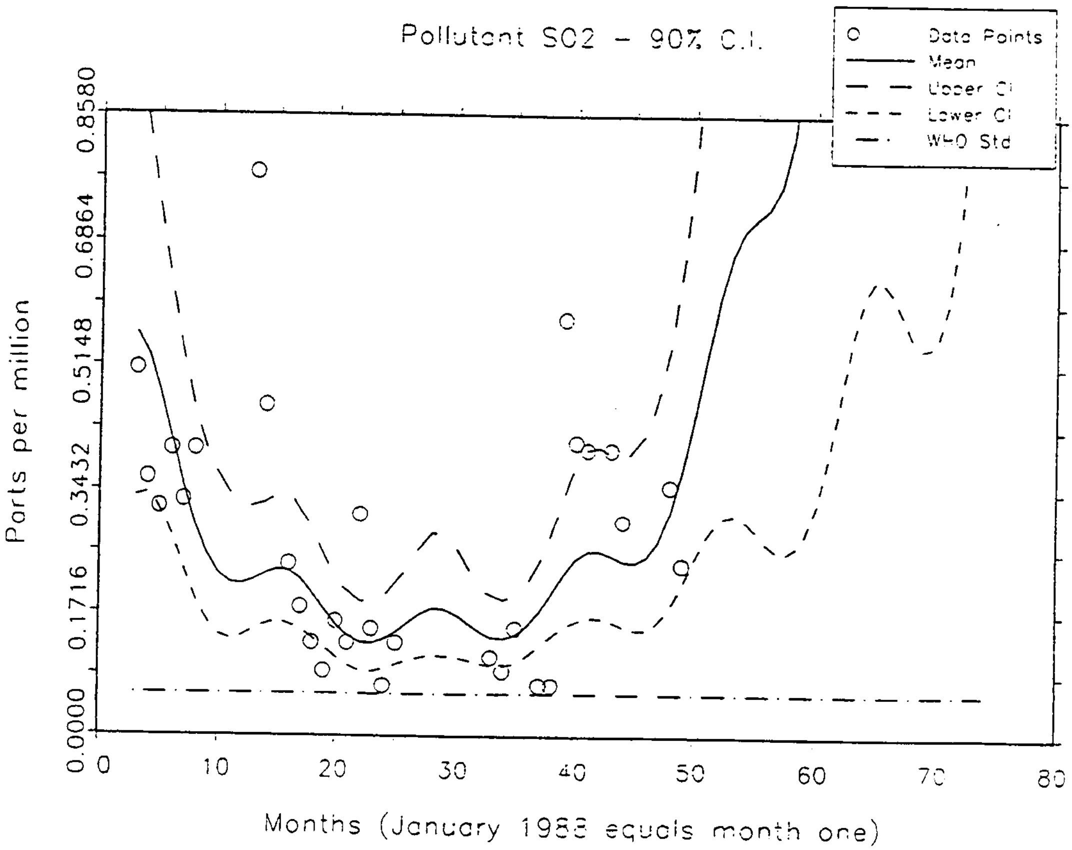

Figure 4. Monthly mean ambient $S0_2$ Levels in Tehran, Iran from 1988 to 1993

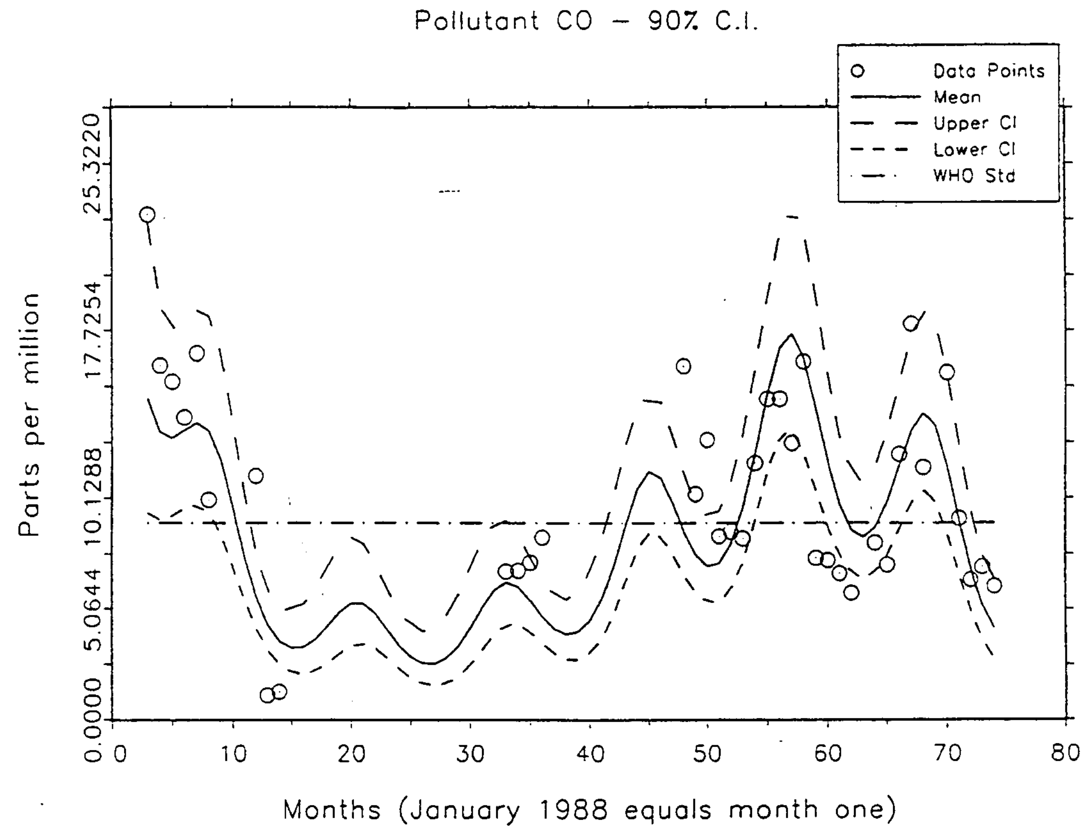

Figure 5. Monthly Mean Ambient CO Levels in Tehran, Iran from 1988 to 1993.

Total Suspended Matter (TSM)

The graph indicates a relatively stationary trend in monthly mean Total suspended matter(TSM) concentrations between 1988 and 1991 (See Figure 6). TSM emissions range from 14.0 µg/m^3 to 166 µg/ m^3. Regression analysis showed a significant trend (p = 0.002, 90% CI). From 1991 to 1993 TSM levels showed an increasing trend in monthly mean concentrations. Maximum TSM concentrations occurred during colder months which is indicated at months October, November and December. Lower concentrations occurred at March , April and May. Extremely high outliers were observed during January and February of 1992 and February, April and October of 1993. From 1991 to 1993 ambient TSM levels increased dramatically, but generally remained below the WHO guideline limit of 150 $\mu g/m^3$.

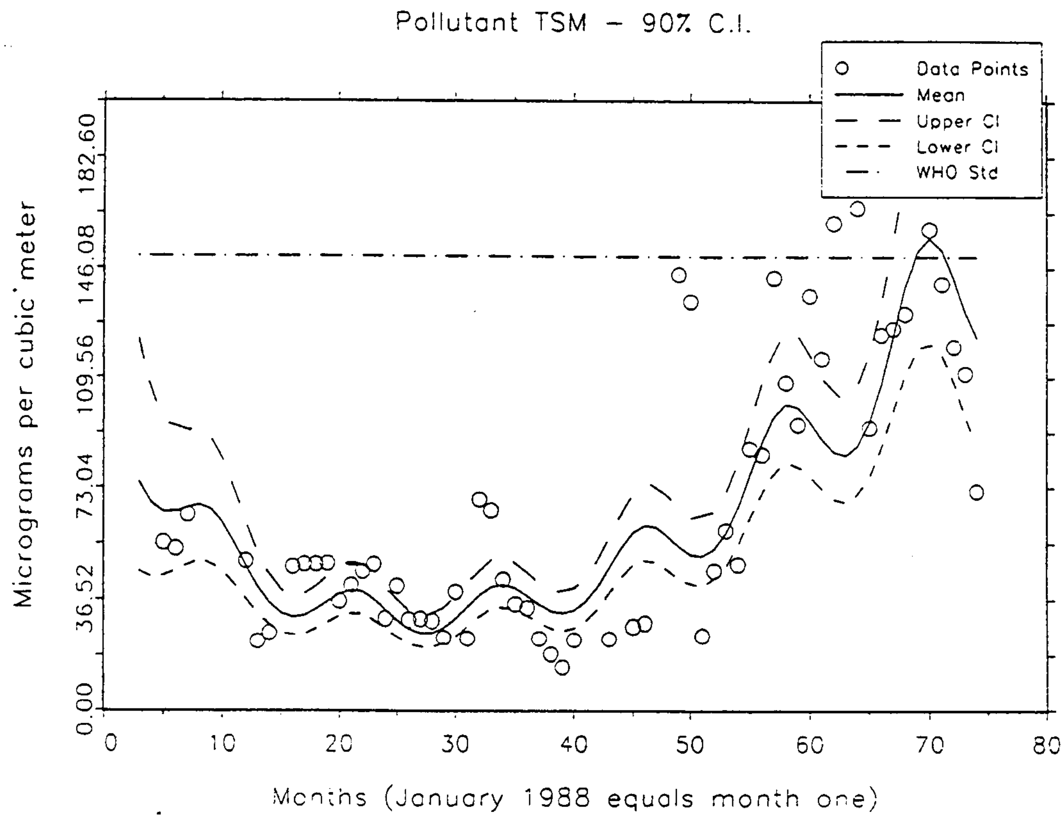

Figure 6. Monthly Mean Ambient TSM Levels in Tehran, Iran from 1988 to 1993

Nitrogen dioxide (NO_2)

Figure 7 shows monthly mean nitrogen dioxide (NO_2) concentrations in Tehran that range from 0.01 ppm to 0.058 ppm during the 1988- 1993 period. Regression analysis showed a significant trend ($p = 0.003$, 90%CI). Higher concentrations of NO_2 occurred during the colder months as indicated at months November, December and January. Lower concentrations occurred during March, April and May. An extremely high outlier was observed in November 1992. Although NO_2 emissions are well above WHO standards from 1988 to 1991, emissions decreased to below WHO standards (0.052 ppm) in 1992 and 1993.

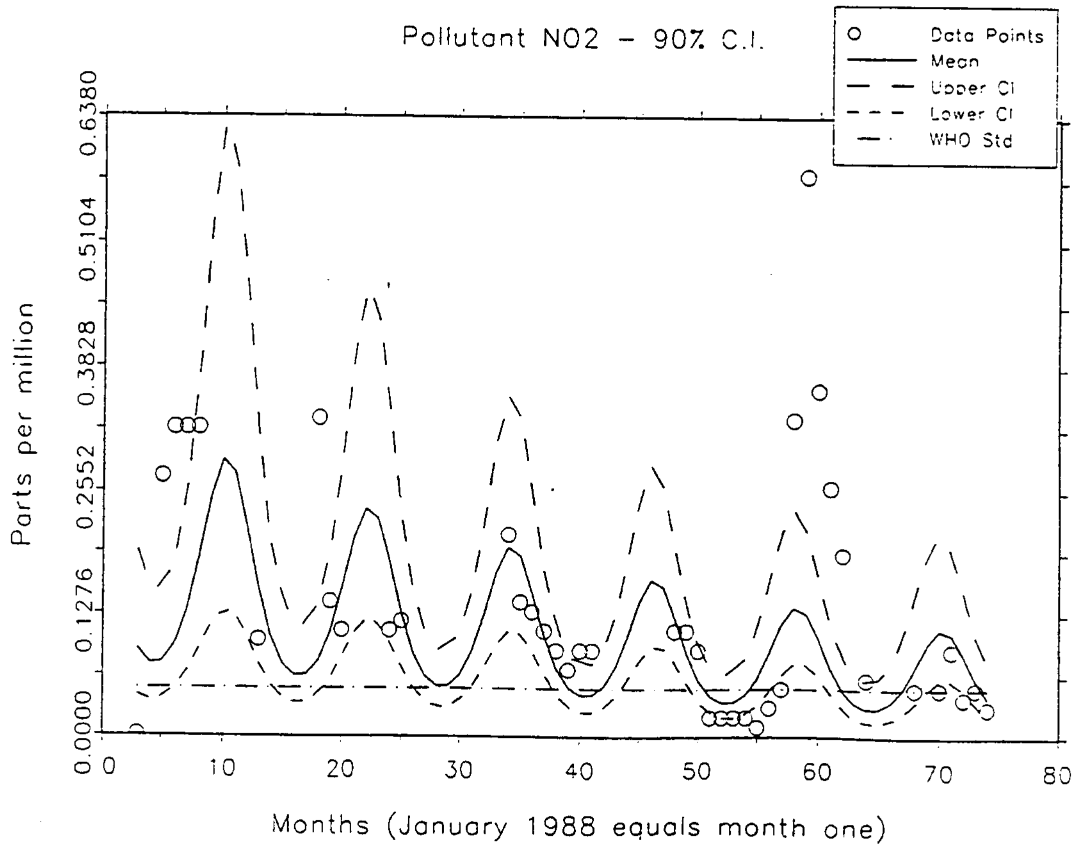

Figure 7. Monthly Mean Ambient NO_2 Levels in Tehran, Iran from 1988 to 1993.

Hydrocarbons (HC)

Figure 8 shows monthly mean concentrations of Hydrocarbons (HC) in Tehran that range from 0.100-8.900 ppm from 1988 to 1993. Although the regression analysis results showed a significant trend (p = 0.000, 90% CI) missing data from 1988 to 1992 was a limiting factor in this analysis. A more complete analysis on a monthly basis of the available data from 1992 to 1993 shows an increase in HC levels with high concentrations during summer as indicated at months June, July and August. Lower concentrations occurred during January and February. WHO guidelines (0.24 ppm) are exceeded throughout this period. Highest HC levels in Tehran were 37 times greater than WHO guidelines.

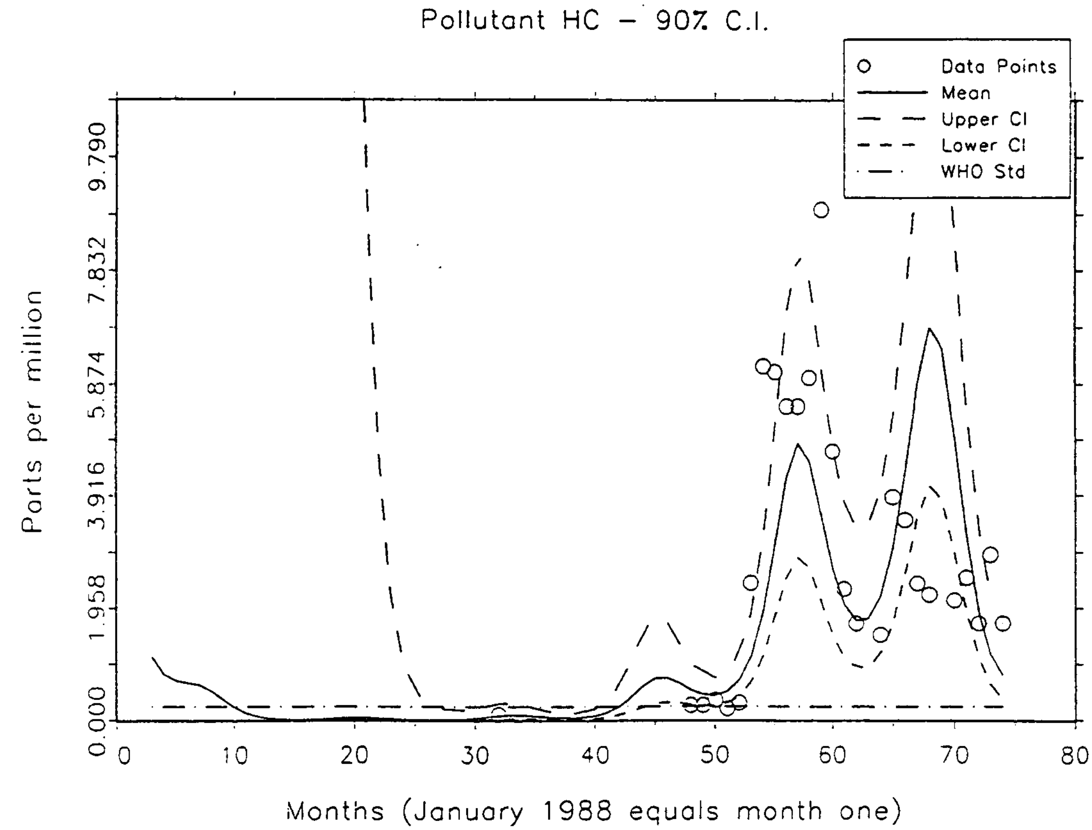

Figure 8. Monthly Mean Ambient HC Levels in Tehran, Iran from 1988 to 1993.

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Interpretation of Trends

Sulfur dioxide (SO_2)

The main source of SO_2 emissions in Tehran are diesel fueled motor vehicles, residential and commercial stoves, heating facilities and oil refineries (Iran-EPA, 1994). About 12 tons of SO_2 are emitted daily in Tehran and 5 kilotons per year (Iran-EPA, 1994). The seasonal cycle in Figure 2 revealed increased levels of SO_2 during winter months and lower levels in summer, which likely resulted from meteorological factors such as atmospheric stability, inversions, and seasonaly changes in speed and direction of the wind (Bellomo et al., 1984; Eagleman, 1991). For example, in Tehran during winter, the instability of the atmosphere and inversions can increase pollutant concentration. Inversions mostly occur during cold winter nights, and will increase the concentration of contaminants during the day (Iran-EPA, 1994; Bellomo et al., 1984). Another reason might be due to less favorable atmospheric dispersion conditions during winter due to Tehran's surrounding mountains that trap the pollutants and lower wind speed (Iran-EPA, 1994). It might also be function of fluctuation in the demand for heating during different seasons. For instance, the use of oil in home heating units during winter time can cause the sulfur content of these fossil fuels to oxidize during combustion and contribute to increased levels of SO_2.

SO_2 levels are expected to increase at a fast rate if no action is taken to reduce SO_2 content of diesel fuels in vehicles and heating facilities (Iran-EPA, 1992, WHO, 1992). Long term exposure to elevated levels of SO_2 and TSM (if the following trend continues) that are above WHO guidelines might result in adverse health effects for susceptible populations such as increased frequency and respiratory infections in children, and more general respiratory symptoms such as coughs, sneezing, and shortness of breath for all who are exposed (Toulomi, 1994; Watson et al., 1988). Owing to the number of motor vehicles, and the distribution of industries and population, SO_2 and TSM levels seem to be higher in south and south western parts of Tehran. They tend to be lower towards the north due to lower population density and lack of industries (Iran-EPA, 1994). Additional toxic compounds released from the burning of household waste and tires release toxic compounds that pose a considerable health risk to the population affected by the smoke(WHO, 1992).

Carbon monoxide (CO)

Exhausts from petrol motor vehicles are the largest source of CO emission in Tehran (Iran-EPA, 1994). About two million vehicles used in transport such as cars, buses, minibuses, taxis, trucks and vans use approximately 6.3 million liters of leaded gas and 8.6 million liters of gasoline per day (Iran-EPA, 1994). These vehicles average 12 million trips per day. An average car in Tehran emits as much as 63 g/km of CO, which adds up to 2100 tons per day and 766.5 kilotons per year (Iran-EPA, 1994).

The upward trend in CO concentration from 1991 to 1993 might be due to an increase in the number of poorly maintained public and private transport vehicles that have few functioning emission controls. Congested urban centers with crowded streets often have high concentrations of CO (WHO, 1992). Because roads are not wide enough, on-street parking and lack of coordinated traffic signals interferes with traffic, often causing stop and go operation that result in increased CO emissions (Iran-EPA, 1994). The results indicated a seasonal variation with higher levels of CO during summer months might be explained by the presence of surface temperature inversions and low wind speed that favor high levels of CO, and are typical in the summer time (Bellomo et al., 1984 ; & Eagleman, 1991). This upward trend in CO levels is likely to increase in the future given the number of increasing motor vehicles and inadequate traffic management situation (Iran Traffic Department, 1992; WHO, 1992).

The upward trend in CO levels is cause for concern. High CO levels above 0.023 ppm may result in high concentrations of COHb blood levels. Symptoms of long term exposure to CO are associated with increased heart disease, headache, fatigue, and decreased athletic performance (WHO, 1992; Raloff, 1995). As discussed earlier, increased CO levels may be exacerbated by slow moving traffic or heavy vehicle density, such as found in southern and central parts of Tehran. Health effects may, therefore, be worse for people with higher exposures, such as bus drivers and road-repair workers. Individuals with anemia, emphysema and cigarette smokers are at higher risk (WHO, 1992; Allerd, 1989).

Total Suspended Matter (TSM)

Diesel vehicles, old cars, buses and trucks, industries, commercial and residential heating and traditional baths and bakeries are the main sources of TSM in Tehran (Iran-EPA, 1994). About 11 tons of TSM per day and 4.0 kilotons per year result from motor vehicle emissions, alone, and this amount corresponds to only 9% of the total TSM emissions (Iran-EPA, 1992). According to the WHO report (1980), TSM levels in the early 1980s in Tehran greatly exceeded WHO seven-day guidelines. In fact, Tehran exceeded these guidelines on more than 200 days a year. Earlier records showed a sharp decrease in TSM concentrations from 1980 to 1988 (See Figure 6). This decrease is puzzling, as there were no control measures aimed at improving pollutant concentrations during that period. As indicated in Figure 6, there was a decreasing trend in TSM levels from 1988 to 1991 to well below WHO guidelines. This might have occurred due to planning measures such as motor vehicle restrictions, promoting the use of compressed natural gas by taxis and expansion of green space within residential parts of Tehran (Iran-EPA, 1994). However, the increasing trend in TSM levels from 1991 to 1993 as indicated in Figure 6 shows that ambient TSM concentrations are likely to increase in the coming decade unless more comprehensive and stringent control measures are adopted.

Nitrogen dioxide (NO_2)

In Tehran the majority of NO_2 emissions arise from motor vehicle exhaust (Iran-EPA, 1994). Diesel powered vehicles also contribute to NO_2 emissions. NO_2 emissions were estimated to be 86 tons per day and 31.39 tons per annum in 1994 (Iran-EPA, 1994). As demonstrated in Figure 7 decreases in NO_2 concentrations in 1992 and 1993 might have been due to restrictions of diesel powered vehicle use in central parts of Tehran and the replacement of leaded gasoline by natural compressed gas in 6000 taxis (Iran-EPA, 1994). Figure 7 also shows higher NO2 concentrations in colder weather. It is difficult to explain high NO_2 concentrations in colder weather based upon temporal variations in emissions, because dramatic shifts in transportation behavior are not expected from season to season. An alternate explanation may be meteorological and geographical factors such as wind speed, wind direction, atmospheric ventilation, insolation and surrounding mountains may contribute to the trapping of air and increasing levels of NO2 over time (Eagleman, 1991).

While NO_2 concentrations appear to be decreasing over time, continued increase in the motor vehicle population and inadequate control measures might reverse this trend. It may be that NO2 levels will increase, or that secondary pollutants such as ozone will likely form during the warmer months due to increased insolation, higher temperatures and greater stagnation (Bellomo et al., 1984; WHO, 1992). At present ambient O_3 concentrations are not measured by Iran's EPA. Tehran's climate and topography combined with increasing levels of photochemical pollutants, however, suggest that O_3 may be exacerbated by increased levels of NO_2 (Iran-EPA, 1994; WHO, 1992).

NO_2 levels show a decreasing trend as compared to the other pollutants and ambient NO_2 levels fluctuate around the WHO guideline. Concern is warranted, however, with the predicted increase in the number of motor vehicles, limited parking space, and inadequate pollution control strategies. NO_2 concentrations are likely to increase at a fast rate. Exposure to NO_2 emissions above the WHO guidelines may increase susceptibility to respiratory infections such as bronchitis and pneumonia (WHO, 1992).

Although ozone levels are not measured it is generally recognized as being the most irritating and toxic secondary air pollutant that can result in respiratory health effects. Ozone is formed through a series of photochemical reactions between other pollutants (mainly NO_2 and HC) and oxygen (Stern et al., 1984). High levels of NO_2 and HC and frequent sunshine in Tehran could result in high levels of O_3. Levels of O_3 that exceed health based standards may produce irritation of mucous membranes of respiratory system causing coughing, impaired lung function, headaches, and reduced resistance to colds and pneumonia (WHO, 1992) .

Hydrocarbons (HC)

The main sources of hydrocarbons (HC) in Tehran are motor vehicles, petrol evaporation, leaks from gasoline transportation tanks and residential stoves and heaters (Iran-EPA, 1994). In 1994 estimated HC emissions totalled 382 tons per day and 139.43 per annum (Iran-EPA, 1994). HC emitted by an average car in Tehran is about

5.2 g/km. According to Iran's EPA the missing data for the monthly mean levels of HC from 1988 to 1991 was due to lack of funds, inadequate personnel, technical difficulties, and power cuts (Iran-EPA, 1993). HC concentration levels peaked during colder months and were lower during warmer months. This may be explained by Tehran's geographical situation such as surrounding mountains that trap the polluted air and lower wind speed during colder months (Bellomo, 1984; WHO, 1992). It may also be due to and increasing demand for heat during winter that increases the amount of gasoline leaks. As demonstrated in Figure 7 even though HC concentration levels were at low levels in 1993, these levels are expected to increase in the future mainly because of increasing traffic (WHO, 1992).

As seen in figure 8, HC concentration levels were well above WHO guidelines. Long term exposure to these photochemical pollutants suggest a high potential for health related problems including onset of respiratory illness in children and the elderly, and increased asthma attacks in adults (WHO, 1992). Low- molecular weight compounds can cause unpleasant effects such as eye irritation, coughing and sneezing and drowsiness. Heavy -molecular weight may have carcinogenic or mutagenic effects (Watson et al., 1988).

The existing data and the trends in air pollution levels in Tehran from 1988 to 1993 suggest that there is concern for the population residing in this area. Ambient pollution levels exceeded the WHO guidelines by SO_2, CO, NO_2 and HC. Of health-based note is the effect of pollutants on communities who live in high emission areas.

Additional Political and Social Factors

Various political and social factors inhibit the implementation of adequate control strategies in Iran, and put some groups at higher risk than others. Other factors such as the health status of the group exposed, housing conditions, medical care, water supply, and nutrition will inevitably influence the health of Tehran's residents (WHO, 1992).

There are areas in Tehran (south, south west, central) that are normally populated by low income groups with inadequate health care (M.Shirazi, personal communication, April 1995). Air pollution in these areas comes mainly from motor vehicles with polluting fuels, and insufficient residential and commercial stoves (Iran-EPA, 1994). The fact that poorer groups live in much more cramped and overcrowded conditions increases the risk of disease transmission (WHO, 1992). A second issue has been that the government's main concern has been the survival of the national economy, and no doubt its own survival, and priorities are increasing exports and creating jobs (Hamshahrie, 1994). Therefore, implementing environmental legislation or conducting regular air quality monitoring programs and gathering epidemiological data to ascertain environmental and health risks have not been a high priority.

The Iranian government's response to the problem of air pollution has not been proactive. The EPA does not have a long term air pollution control program, nor does it have basic information required for such a program such as on going air quality data, emission inventories and epidemiological data related to health effects of air pollution (F. Ramazan, personal communication, January 1996). For example the incomplete data encountered in this research were due to conditions that resulted from an eight year war with Iraq that cost Iran between $700 billion and $1 trillion, and years of economical sanction (Iran-EPA, 1994). Low research budgets have limited the acquisition and analysis of data, and to date research capacity is far behind research needs (IRDC, 1992; M. Shirazi, personal communication, April 1995). These problems put Iran at a great disadvantage, as scientists and policy makers lack the basic data to analyze the significance of environmental pollution problems. Resources for conducting primary research are extremely limited. Universities that do have environmental research programs are over crowded, and staff are demoralized by poor pay, excessive work load and inadequate equipment (F. Dabir, personal communication, November 1994). Most of the data that do exist are unreliable or out dated.

Another problem in acquiring reliable data is that air pollution data is disclosed in government reports that are often classified "confidential" if considered to be controversial or embarrassing to the authorities. The community does not have access to confidential materials (F. Dabir, personal communication, June 1994). The lack of public access prevents local citizens from being aware of pollution problems and prevents them from being involved in solving them . Local people have historically had limited access to information that would help them understand the problems and be involved in the decision-making process.

The existing environmental laws are poorly enforced, and are too lenient on polluters. In some cases bribery has lead to the approval of environmental destructive and socially damaging projects, resulting in the approval or importation of environmentally damaging products (M. Monfared, personal communication, November 1995)

Conclusions

The purpose of this study was to determine trends in Tehran, Iran's air quality levels between 1988 and 1993 and to report changes that have occurred during this period that may affect human health.

From the available data it can be concluded that there was an upward trend in air pollution levels in Tehran for all the measured pollutants except for NO_2 during the years 1988-1993. It is also concluded that WHO guidelines were substantially exceeded by all pollutants except TSM. Much of the upward trend is likely to be due to unfavorable pollutant dispersion conditions and the continuing increase in population growth and motor vehicle traffic. It is expected that the growth in population and the number of motor vehicles in Tehran will increase the air pollution levels above the present concentrations.

Nitrogen dioxide emissions noticeably decreased in 1992 and 1993 and were usually within or below WHO guidelines. This trend , however, is likely to change with the continued increase in the number of motor vehicles.

Sulfur dioxide levels demonstrated an increasing trend after 1990, and exceeded the WHO guidelines throughout the period. Sulfur dioxide levels appear to be higher in winter and lower in summer months reflecting increasing diesel vehicle emissions and domestic and industrial heating.

Carbon monoxide emissions increased from 1991 to 1993 which is also likely due to increased motor vehicle traffic over the same period. Maximum CO concentrations occurred in summer months which may have been aggravated by meteorologic conditions. CO concentrations exceeded WHO guidelines after 1991.

Hydrocarbon concentrations demonstrated no clear trend due to lack of adequate data. Data that was analyzed, however, exceeded WHO guidelines.

Total suspended matter values were below WHO guidelines during the period 1988 to 1991 showed a dramatic increase from 1991 to 1993. The upward trend is expected to continue and even exceed WHO guidelines in the future based on the increase in the number of motor vehicles and lack of adequate pollution control measures.

The data findings suggest that long term exposure to air pollutant levels that exceed WHO guidelines are likely to have come from motor vehicles and industrial sources. As the population growth continues, and increasing numbers of motor vehicles are driven in Tehran, there is concern for the health effects that may be caused from these pollutants. Although this study did not investigate epidemiologic records related to air pollution, other evidence suggests that increasing levels of pollutants will increase morbidity and the development of chronic pulmonary conditions in highly exposed individuals depending on their age, state of health, and level of exposure. In general, children, pregnant women, and older people living in or commuting to south Tehran are likely to be more susceptible, as these are considered to be at risk populations.

Recommendations

The results indicate the lack of a continuous monitoring program in Tehran that is required for assessing the magnitude of the problem and implementing effective solutions. Air pollution problems in Tehran depend on a combination of factors such as: geography, climate, social and economic conditions, infrastructure, and resource availability. There are a wide variety of interventions available that can improve Tehran's air quality, but appropriate solutions vary according to these conditions.

With these considerations in mind it is recommended that air pollution monitoring, including continuous sampling and analytical quality control should be improved in order to obtain continuous and reliable data. The authorities should be encouraged to initiate regular air quality monitoring and to gather epidemiological data as a matter of priority in order to identify environmental and health risks. Measurements of O_3 and Pb should be introduced as well.

A second recommendation is to improve traffic congestion that will result in fuel saving and reduce pollutant emissions. Providing adequate parking space and parking restrictions would greatly improve on-street and side-road parking and help traffic flow. Centrally computerized signal systems and segregation of non-motorized forms of transport such as animal drawn carts can help maintain uniform speed and stable traffic flow. The use of more stringent traffic control measures and heavier fines during auto - free zone days of the week in the central part of Tehran may also reduce pollutant emission. Improving transportation facilities by providing funds for new taxis, buses , and minibuses that operate on compressed natural gas, and encouraging the public to use public transportation and participate in car pooling programs can increase the efficiency of the entire transport system.

The use of clean fuels such as natural gas reduce auto emissions at a lower cost. Iran is one of the largest suppliers of natural gas, so this approach can both be cost-effective and environmentally clean. It is therefore recommended that the government require the use of natural gas by all public transportation such as taxis and buses and create economic incentives by making it cheaper than other fuels. Further use of natural gas especially by industry and by electric power stations should also be encouraged. Meanwhile, reducing or substituting lead in gasoline and sulfur in diesel fuels is one of the most recommended options available to combat air pollution in Tehran. In Iran petroleum products are government owned and subsidized, therefore the government can have an effective role in requiring all buses and government vehicles to operate on unleaded gasoline.

A long term approach, to reduce vehicle emission in Tehran is to replace the existing vehicles with highly efficient vehicles in the future. It is recommended that the automobiles manufactured in Iran must be equipped with emission controls and all existing vehicles be retrofitted with antipollution devices.

A fifth recommendation is that further research regarding air pollution trends in Tehran, Iran be conducted. Scientists, planners and public officials should work cooperatively to collect data and manage information for future strategic planning to reduce the amount and the effect of air pollution. This goal can not be achieved without public involvement and support, therefore, implementation of environmental education and public awareness programs is essential. Environmental education programs could start in schools at an early age , different groups could also be reached through educational programs in mosques and other religiuos centers. Further studies could monitor the effectiveness of the programs and rational decisions can be made about appropriate transportation technology and future control strategies.

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APPENDIX:
AIR POLLUTION DATA FROM TEHRAN, IRAN FROM 1988 TO 1993

```
@shir001.gau - does analysis of Teheran, Iran, air pollution data.@
new;
disable;
library pgraph;
graphset;
output file=shir001.out reset;
"  SHIR001.OUT  " $datestr(date)~timestr(time); ?;
d88={
   0.001 23.02 .    .  0.51,
    .   16.12 .    .  0.36,
   0.27  15.39 .  55.0  0.32,
   0.32  13.78 .  53.0  0.40,
   0.32  16.67 .  64.0  0.33,
   0.32  10.04 .    .  0.40,
    .    .    .    .    .  .,
    .    .    .    .    .  .,
    .    .    .    .    .  .,
   0.91  11.12 .  49.0   . ,
   0.10   1.1  .  23.0  0.78,
    .    1.27  .  25.8  0.46};
d89={
    .    .    .    .    .  .,
    .    .    .  47.2  0.24,
    .    .    .  48.0  0.18,
   0.33    .    .  48.0  0.13,
   0.14    .    .  48.3  0.09,
   0.11    .    .  36.0  0.16,
    .    .    .  41.2  0.13,
    .    .    .  45.7  0.31,
    .    .    .  48.0  0.15,
   0.11    .    .  30.4  0.07,
   0.12    .  13.58 41.0  0.13,
    .    .  15.47 30.0   . };
d90={
    .    .    .  30.3   . ,
    .    .    .  29.7   . ,
    .    .    .  24.3   . ,
    .    .    .  39.0   . ,
    .    .    .  24.0   . ,
    .    .   0.1  69.0   . ,
   0.93   6.8  .  65.47 0.11,
   0.21   6.83 .  43.0  0.09,
   0.14   7.20 .  35.0  0.15,
```

```
   0.13  8.35 .  33.8  . ,
   0.11   .  .  24.0  0.07,
   0.09   .  .  18.7  0.07};
d91={
   0.07   .  .   14.3 0.58,
   0.09   .  .   23.6 0.41,
   0.09   .  .     . 0.40,
    .    .  .    . . ,
    .    .  .  24.0 0.40,
    .    .  .    . 0.30,
    .    .  .  28.0 . ,
    .    .  .  29.0 . ,
    .    .  .    . . ,
   0.11  16.1  0.26 216.0 0.35,
   0.11  10.31 0.26 144.0 0.24,
   0.09  12.75 0.35 135.0 . };
d92={
   0.02  8.4  0.20  25.0 . ,
   0.02  8.6  0.30  46.0 . ,
   0.02  8.3  2.40  59.0 . ,
   0.02  11.7 6.2   48.0 . ,
   0.01  14.6 6.1   86.0 . ,
   0.03  14.6 5.5   84.0 . ,
   0.05  12.6 5.5  143.0 . ,
   0.33  16.3 6.0  108.0 . ,
   0.58  7.4  8.9   94.0 . ,
   0.36  7.3  4.7  137.0 . ,
   0.26  6.7  2.3  116.0 . ,
   0.19  5.8  1.7  161.0 . };
d93={
    .    .    .    . . ,
   0.06  8.1  1.5  166.0 . ,
    .   7.1  3.9  93.0 . ,
    .  12.1  3.5  124.0 . ,
    .  18.0  2.4  126.0 . ,
   0.05  11.5  2.2  131.0 . ,
    .    .    .    . . ,
   0.05  15.8  2.1  159.0 . ,
   0.09  9.2  2.5  141.0 . ,
   0.04  6.4  1.7  120.0 . ,
   0.05  7.0  2.9  111.0 . ,
   0.03  6.1  1.7   72.0 . };
ydat=d88|d89|d90|d91|d92|d93;
```