CHANGING VISIBILITY IN KUWAIT: 1963-1978

by

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ABSTRACT

This thesis documents visibility conditions in Kuwait for the years 1963 through 1978 and attempts to relate changes in visibility to probable sources of pollution, both natural and human. Fluctuations in visibility during the 16-year period are analyzed using a runs test and simple regression techniques on observations divided into four visibility range classes (0-3 km, 4-6 km, 7-9 km, and 10+ km), with observations taken at both 6:00 a.m. and 12:00 noon. The analysis shows little evidence for consistent long-term trends in visibility. The effects of various weather conditions on visibility (fog, mist, high relative humidity, rain, and high windspeed) are investigated using simple and multiple regression techniques and are shown to exert a strong controlling influence. Human activity is shown to be associated with visibility, in that conditions are significantly better on the weekend (Friday) than during the working days, but simple and multiple regressions between a number of measures of human activity and visibility fail to identify specific activities that contribute to a reduction of visibility.

CHAPTER 1

INTRODUCTION

One of the most familiar and undesirable aspects of air pollution is its profound effect on visibility. Since the industrial revolution began in Europe, industrial societies have come to expect and even accept reduced visibility as an unavoidable adjunct to development and prosperity. Reduced visibility is experienced by most industrial communities. In some locations, such as Los Angeles, where the deterioration is well-documented and is a popular topic for discussion, the effects may influence a very large region. One investigator (Leighton, 1973, p. 234) estimates that "97% of the population of California lives in areas where visibility has deteriorated." Dense concentrations of people with high energy requirements, industrial activities, and frequent use of vehicles have a strong tendency to produce a heavy load on the atmosphere and its ability to disperse pollutants.

Visibility changes are being given much attention and have been studied for several decades in highly industrialized western societies, but the awareness, measurement, and understanding of these changes in rapidly developing societies elsewhere are deficient. Most newly developed and developing industrialized societies are intent on improving living standards, education, and health for their people. These basic goals are given much greater attention than problems, such as decreasing visibility, that accompany industrial development.

In this study, I intend to document changing visibility conditions in Kuwait for the years 1963 through 1978 and to relate these to types and probable sources of pollution. In doing this it is necessary to adapt appropriate measures of visibility and extract the data from the extensive volume of observational data collected at Kuwait International Airport from 1963 to 1978. The effects of variable weather conditions on visibility must also be ascertained so that their influence can be controlled and used to simplify the pattern of long range trends.

Direct monitoring of air pollution in Kuwait is recent. There are only limited data to allow conclusions regarding sources and types of pollution and their effects on visibility. For this reason, the relationship between trends in visibility and growth in numerous measures of economic development are explored.

Industrial development is a relatively new phenomenon in Kuwait. Since shortly after the discovery of oil in 1938, the state has viewed industrialization as a strategy to maintain and utilize the benefits provided by this valuable resource. The state has embarked on a program for industrialization of the country, initiated in 1961 when the government implemented its policy of direct participation with private enterprise in industrial ventures. The objective was, and is still, to use national resources, principally oil and natural gas, by establishing industries associated with these commodities (Shankland-Cox Partnership, 1977).

With development of the Shuaiba Industrial Area, many environmental problems, particularly air and water pollution around industrial sites, began to emerge. In order to minimize these problems the state authority established air and water pollution control departments in several different state ministries. Most of these departments, including the Air and Water Control Center of the Shuaiba Industrial Area, the Occupational Health Section within the Ministry of Public Health, and the Kuwait Institute for Scientific Research, have been concerned with sources of pollution as well as with the control and elimination of pollutants. These efforts have increased public awareness of pollution problems and support for their control. There have also been several recent conventions and meetings called to discuss such topics as environmental protection and air and water pollution within the community.

Compared to the industrial nations of the west, pollution problems, public awareness of these, and attempts to find solutions are all recent phenomena in Kuwait. The consequences with respect to several aspects of the environment, including visibility, are as yet poorly documented (Hijazi, 1975, pp. 124-127).

Kuwait's Geographic Setting

Before discussing atmospheric visibility and air pollution in Kuwait, it is necessary to provide a general introduction to the geography of the state.

The State of Kuwait is situated on the northwestern shore of the Arabian (Persian) Gulf, between latitudes 28° and 30° north, and longitudes 46° and 48° east (Figure 1). It is bounded on the east by the Arabian (Persian) Gulf, on the south and southwest by the Kingdom of Saudi Arabia, and in the north and west by the Republic of Iraq. Kuwait

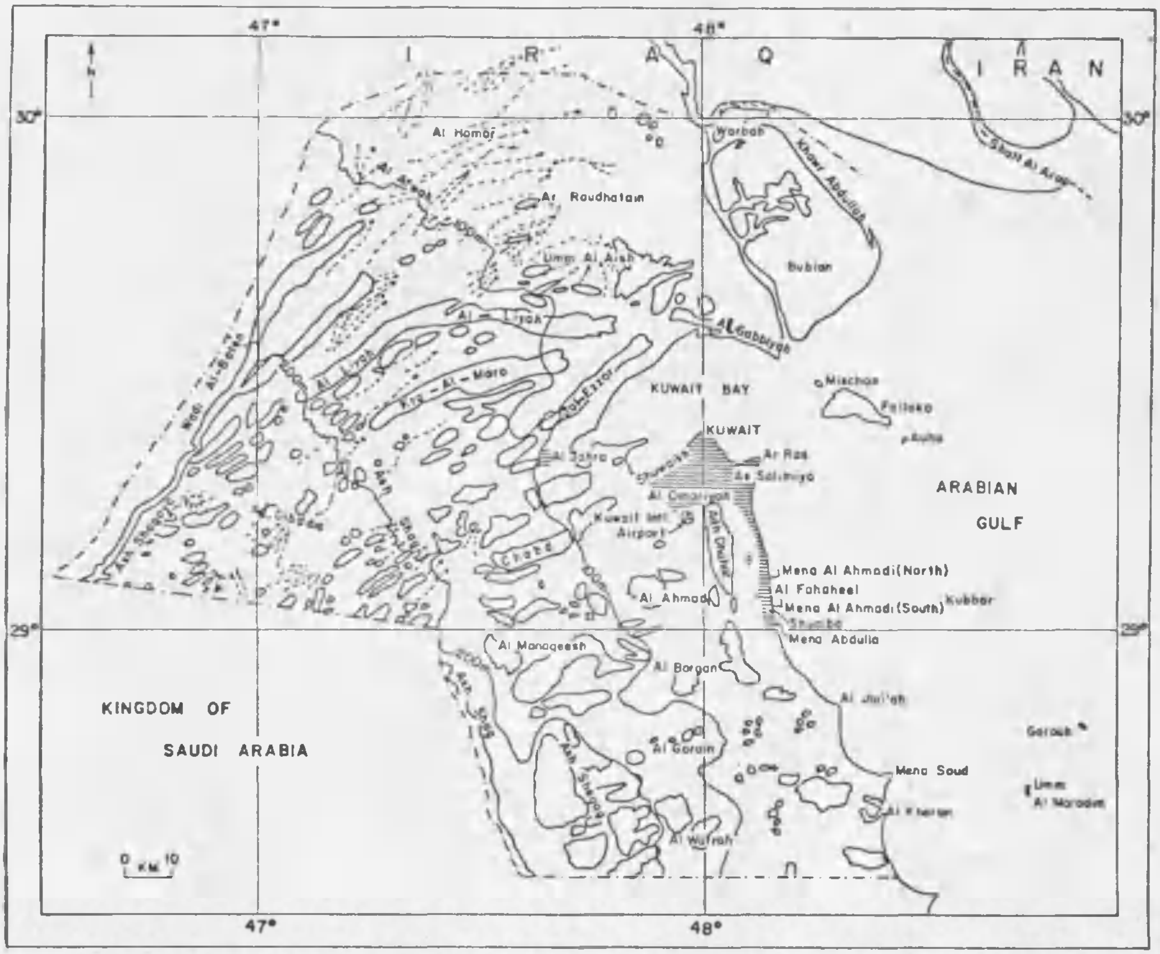


Figure 1. The State of Kuwait-- From Al-Kulaib, 1974.

is a small country with a total area of approximately 17,000 square kilometers (7,000 square miles).

Topographically, the land slopes gently downward from west to east. The land's surface is a fairly regular plain interrupted by a series of small shallow sandy basins and a few rocky hills of maximum heights ranging from 180 to 300 meters above sea level. The highest elevations of the plain, approximately 300 m, are found on the western border of the country (Hijazi, 1975, p. 25). The most prominent hills are Jal-Ezzor near Al Jahra village, "Al-Liyah," and "Kra-Al-Maro." There are numerous dry small drainage ways and shallow valleys of which the most important is Wadi Al-Baten, which extends from southwest to northeast along the border with Saudi Arabia and Iraq. To the east of Al-Baten lies Wadi-Ash-Shagaya, near the frontier with Saudi Arabia. To paraphrase Khalaf et al. (1978, p. 7), the surface of Kuwait is almost completely covered with a layer of sediments composed of a mixture of sand and gravel, or sand and carbonates, especially in the southern portion of the country. These sediments, together with flood plain deposits in southern Iraq and salt flats of the northern Sabkha (fringing Kuwait Bay and Khour Al-Sabbiyah) are probably the principal source areas of dust fallout in Kuwait.

The climate of Kuwait has been described as a "dry, hot, desert type" (Al-Kulaib, 1974, p. 16). The nation has mild winters with a mean January temperature of 12.7°C (Figure 2). Temperatures rarely drop below freezing, although a minimum of -4.0°C was recorded on the 20th January 1964 at Kuwait International Airport (Al-Kulaib, 1974, p. 20). Summers are very hot, with a mean temperature of 37.4°C in July, and a

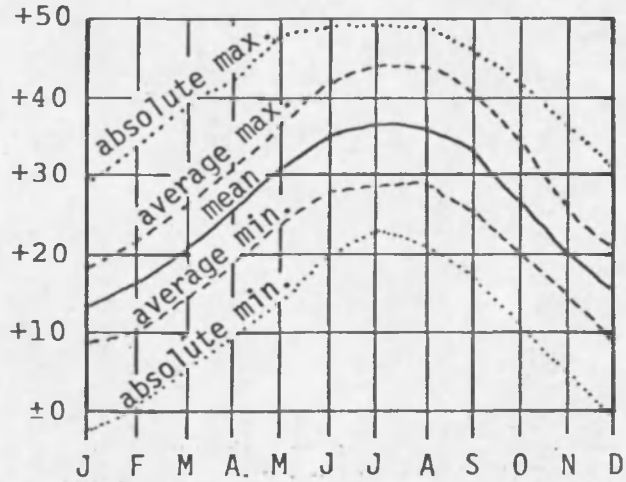


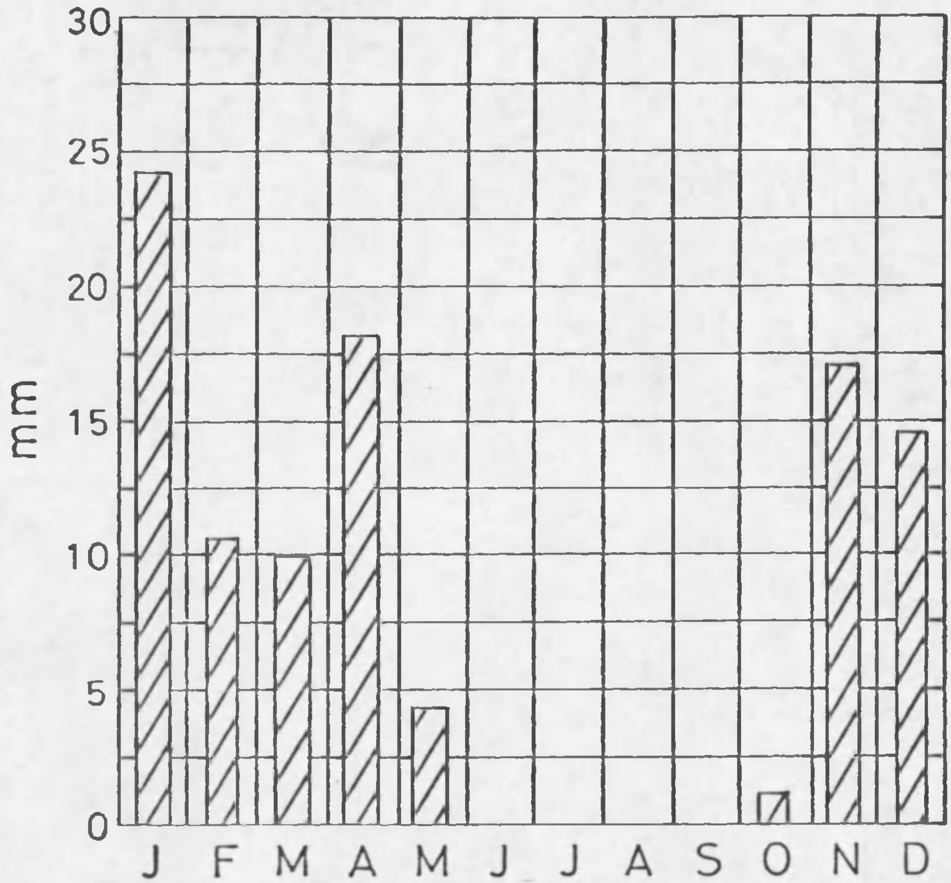
Figure 2. Monthly Temperature Conditions at Kuwait International Airport (in Centigrade)-- From Kuwait, Directorate General of Civil Aviation, 1972.

record maximum of 45°C. Major weather disturbances occur mainly in winter, whereas summer typically has cloudless skies. Rainfall occurs mostly in the winter season. It is characterized by small amounts and great variability (Figure 3), with a mean total of about 100 mm/year. Much of the rainfall occurs during thunderstorms, especially in December and January. Mean relative humidity is about 32%, but annual variation is large, with a minimum in summer (due to hot and dry northwesterly winds), and a maximum in winter. Fog and mist occur mainly in winter and fall. The prevailing winds are northwesterly, but south or strong southeast winds are common during winter months. Great variation in wind direction and speed are associated with dust storms, which occur mainly during June and July (Figure 4).

Sources of Air Pollution in Kuwait

In Kuwait, sources of air pollution are usually classified into two types: natural sources and human sources. The distribution of these sources and differences in the nature, amount and timing of materials supplied from them is closely associated with the country's pattern of settlement.

The developed areas in Kuwait are limited to the coastal strip and occupy a small percentage of Kuwait's total area. Two locations within this strip are the principal human sources, whereas most of the remainder of the nation is barren desert, particularly in the north and northwest. The South Kuwait Industrial Complex, the site of most of Kuwait's petroleum refineries, heavy petrochemical industries, and some other light industries, is located on the southern coast. The second industrial area is Shuwaikh, immediately west of Kuwait City (Figure 5).



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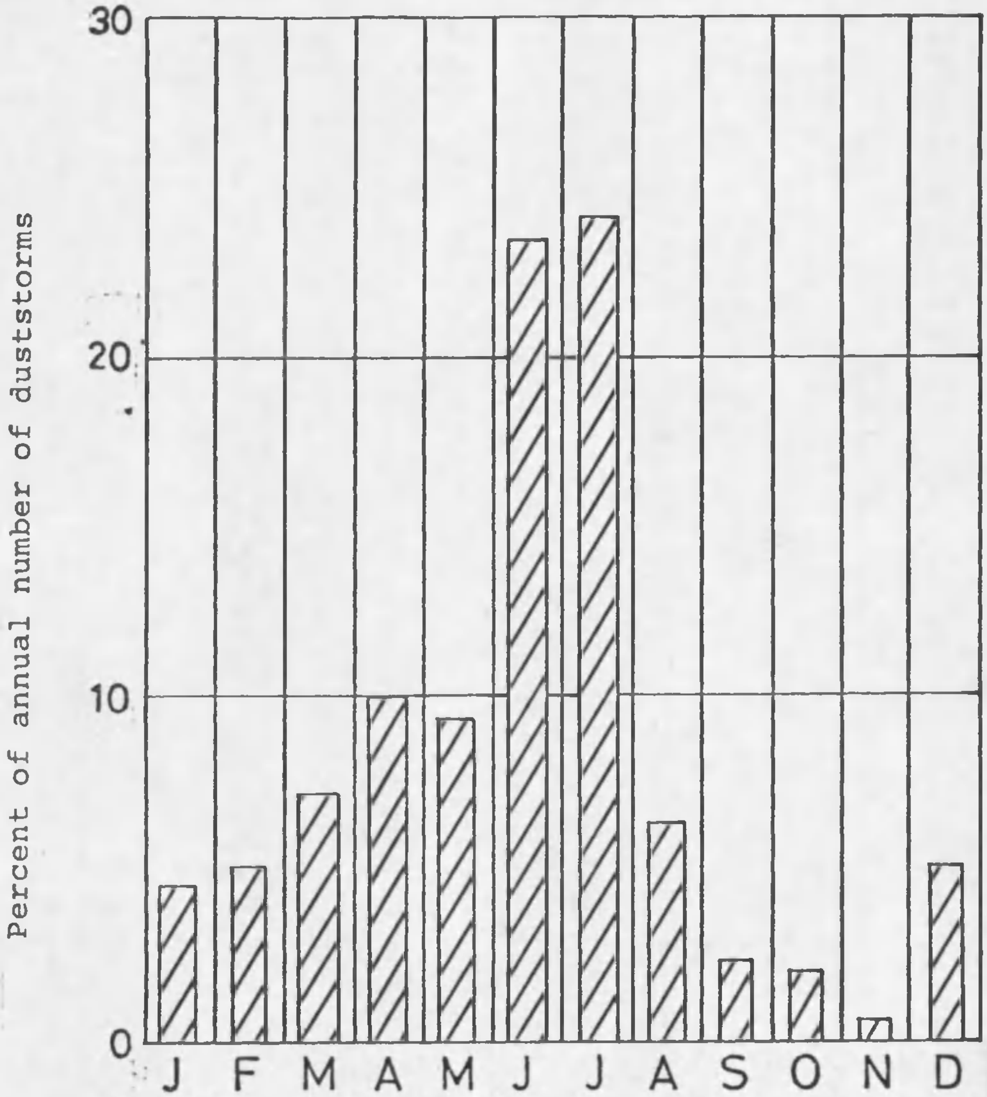

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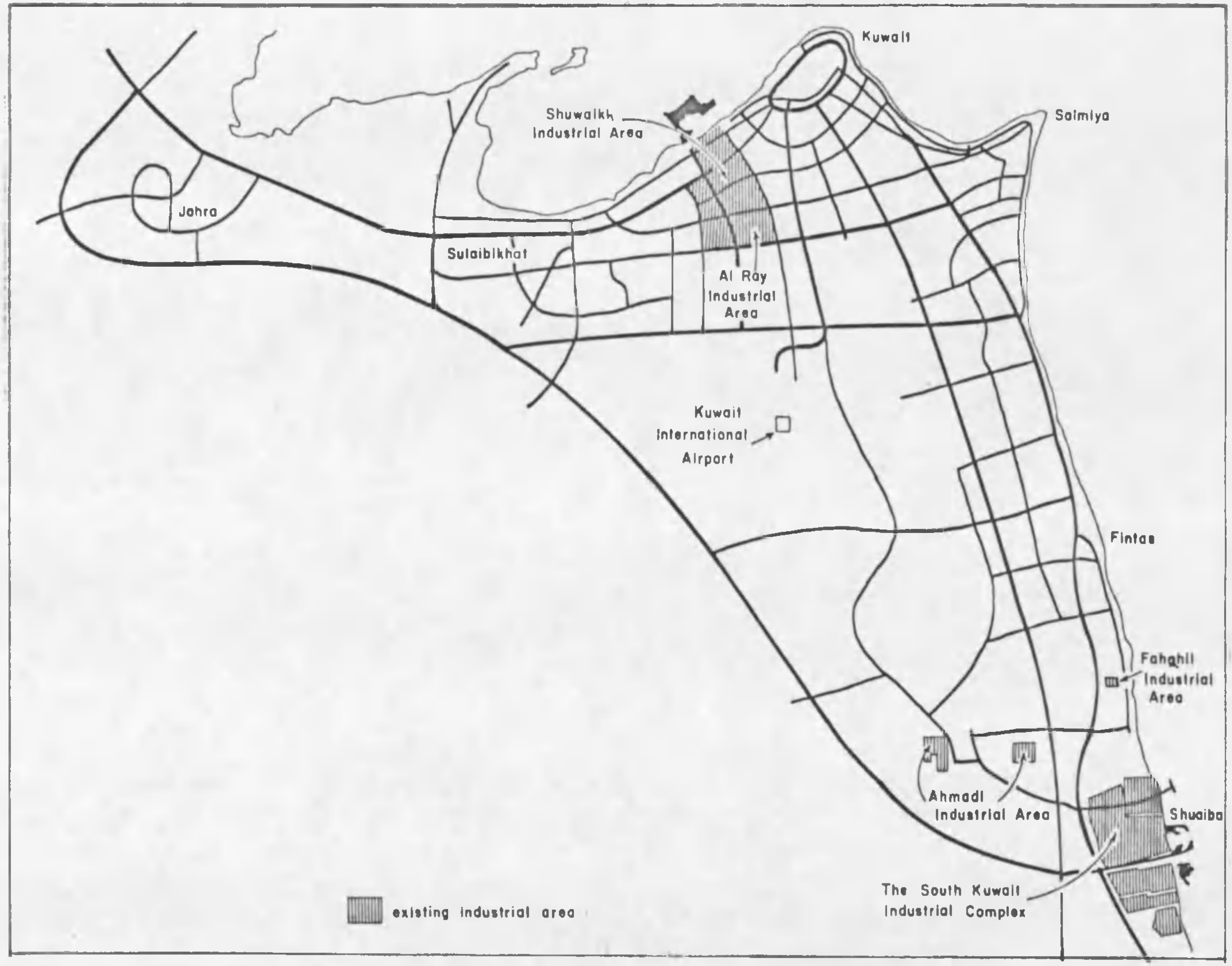

Figure 5. Existing Industrial Areas in Kuwait-- From Buchanan and Partners, 1971a.

As Hijazi (1975, pp. 20-21) concluded, "natural or physical atmospheric pollution is a reflection of the geographic conditions of the country including topography, soil conditions, and climate (windspeed and direction, rainfall, relative humidity, and other weather phenomena)." The atmosphere carries solid particles of varying character and size in suspension, often for long distances. This "dust" is considered a pollutant and plays a major role in regulating visibility in both the settled and uninhabited parts of Kuwait.

Dust storms and sand storms are endemic to the area surrounding the Arabian Gulf (Hijazi, 1975, p. 21). Dust generated locally may contribute considerably to pollution. Khalaf et al. (1978, p. 7) examined the mineralogical composition of dust in June, July, and Setpember of 1978 and concluded that

> dust storm sediments of Kuwait are most probably derived from the dry flood plain deposits in south Iraq. The northern Sabkha, fringing Kuwait Bay and Khour-Al-Subbiyah, might be a source of the dolomite in the sediments. The surface deposits of northwestern Kuwait (Al-Dibdibba formation) could be responsible for the presence of feldspar in Kuwait dust fallout.

In Kuwait dust storms are known as "Touz." The occurrence of Touz in winter is attributed to southeasterly winds accompanying or preceding cyclonic storms. In summer, dust is associated with northwesterly winds blowing out of the interior as a result of the Indian monsoons.

In addition to these dust and sand storms, moisture in the air affects visibility and may also influence atmospheric pollution. According to Kuwait Ministry of Public Health (1978, p. 9), "sizes of aerosol particles at high relative humidity can be larger many times over that in dry state. The water content is influenced by the chemical nature of the aerosol." Fog and mist, which are relatively common in winter, are not normally considered to be pollutants, but these may combine both physically and chemically with man-made pollutants and contribute to the occurrence and persistence of haze.

Frequent temperature inversions, particularly during the cooler months, inhibit the dispersion of all types of pollutants. These widespread conditions are perhaps the fundamental regulators of pollution and visibility levels in Kuwait, and represent an environmental limit for all attempts to control pollution levels and improve visibility.

Man-made sources of air pollution are concentrated mainly in two major industrial areas (Figure 5). The Shuwaikh Industrial Area contains a concentration of light industries. It occupies some 1000 hectares immediately west of Kuwait City and forms an intensive area of development contiguous with the city. The Shuwaikh Industrial Area, including its port, power station, water distribution plant, cement products factory, brick factory, asbestos factory, and the offices of the National Industries Company, was, until 1972, the largest and most diversified industrial area in Kuwait. In 1971 only a quarter of the land was occupied by firms that could be classified strictly as manufacturing and another quarter by firms connected in some way or other with the repair, servicing, and sale of vehicles (Buchanan and Partners, 1971a, p. 39). According to studies done by Hassan (1974) and Al-Dousuki <u>et al.</u> (1974), air pollution from the asbestos factory is one of the most harmful pollutants affecting people, particularly in the area close to the factory (the Al-Omaria residential area).

The South Kuwait Industrial Complex covers the coastal strip from Mina Al-Ahmadi to Mina Abdula, and includes the Shuaiba Industrial Area which was established in 1964. The complex is situated 50 km to the south of Kuwait City, and about 100 km north of the Saudi border. Since 1964, this complex has grown to include the following: 1. Shuaiba South Power and Water Production Station; 2. Shuaiba North Power and Water Production Station; 3. The Petrochemical Industries Company; 4. Kuwait National Petroleum Company; 5. Kuwait Industrial Refinery Maintenance and Engineering Company; 6. Kuwait Cement Company; 7. United Fisheries of Kuwait Company; 8. Kuwait Sulphur Company; 9. Industrial Gases Establishment; 10. Packing and Plastic Industries Company; 11. Dresser (Kuwait) Company; 12. Refrigeration and Oxygen Company (Shuaiba Area Authority, 1976-77, p. 21). Of these industries, the petroleum industry (including both refining and petrochemical manufacturing), is the most important in terms of number of firms, number of workers, and value to the Kuwaiti economy (Shankl-Cox Partnership, 1977, p. 73). The Shuaiba Area Authority established its Air and Water Pollution Control Department within this area. According to Buchanan and Partners (1971b, p. 33), there are two kinds of air pollution:

> . . . attributable to the oil refineries. First, the gas flares let off large quantities of sulphur dioxide into the atmosphere: the ground-level flares (such as those of Kuwait Oil Company) cause greater nuisance than the flares from stacks (such as those of the Kuwait National Petroleum Company and of Aminoil). For example, the maximum concentration of sulphur dioxide occurs within one kilometre of the Aminoil flares, and therefore the nuisance is less serious because it is localised. The evaporative pits at the Aminoil refinery are the second source of air pollution; in these pits oil and water are separated and the hydrogen sulphide released is potentially harmful to people.

Also, the Air and Water Pollution Control Department has studied the South Kuwait Industrial Complex for several years. One of its reports (Shuaiba Area Authority, 1976) identified the main air pollutants as sulfur compounds, nitrogen compounds, and inorganic solid matters, as well as sulfur dioxide, hydrogen sulfide, ammonia, nitrogen dioxide, hydrocarbons, urea dust and cement dust.

In addition to these two main industrial areas, there are other minor industrial areas that contain some light industries. These are: Al Ray Industrial Area south of the Shuwaikh Area, Fahahil Industrial Area north of the Shuaiba Industrial Area, Ahmadi Industrial Area east of Ahmadi City and about 40 km to the south of Kuwait City, and areas of industry in Kuwait City. The Ahmadi Area includes some light petrochemical firms in addition to its dominant construction firms.

Other serious non-industrial pollutants are exhaust fumes from motor vehicles, smoke from burning refuse, and gas burning in oil fields. There are about 2000 oil wells distributed mainly at Ahmadi, Magwa in the south, Rawdatain, Bahra, and Sabraia in the north of the country, in addition to the wells on the Kuwait-Saudi Arabia border (Hijazi, 1975). Among the man-made air pollutants, gases (particularly sulfur oxides) originate from fuel consumption, gas burning in oil fields, and petroleum refineries. Al-Dousuki and Hadi (1974, p. 8) have studied these sources and also numerous incinerators. They concluded that the area around the incinerator, which is situated 25 km west of Kuwait City in the Al-Jahra area, is subjected to some degree of gaseous pollution resulting from burning the trash. The Sulaibikhat and Al-Jahra areas are intolerable when the wind blows toward them.

Other human activities are also responsible for increased dust, such as dust generated locally from bare lands and unpaved roads by moving traffic, grazing animals (especially in the desert area north and west of Kuwait City), agricultural activity (clearing and tilling lands) and clearing the bare lands for construction.

Measurement of Visibility

Deterioration of visibility over time has been examined in numerous studies dealing with climatic modification and the environmental impacts of urbanization. In these studies, the definitions and measurements employed vary widely. It is advisable to consider these topics in detail before discussing methods of documenting and analyzing visibility changes in Kuwait.

The term "visibility," when used by meteorologists, denotes atmospheric transparency or clarity. As Holzworth (1961, p. 71) points out, however, operational definitions are more properly "visual range," or the greatest distance at which prominent objects can be seen and recognized. Robinson (1962a, p. 222) quoting from the Glossary of Meteorology, defines "visibility" as:

> . . . the greatest distance in a given direction at which it is just possible to see and identify with the unaided eye: a) in the daytime, a prominent dark object against the sky at the horizon, and b) at night, a known, preferably unfocused, moderately intense light source. After visibility readings have been determined around the entire horizon circle, they are resolved into a single value of "prevailing visibility for reporting purposes."

It is important to note that visibility readings reported in weather station records are a composite value for the horizon and do not necessarily represent visibility in any single direction, nor the maximum distance of view. Prevailing visibility, the figure normally reported, is defined as "the greatest visibility which is attained or surpassed around at least half of the horizon circle, but not necessarily in continuous sectors" (Robinson, 1962a, p. 222). According to Robinson (1962a), "for the best determinations, during daylight hours, the markers should be black, or nearly black objects standing against the horizon sky."

After visibilities have been determined at several points around the horizon circle, individual observations are resolved into a single value of "prevailing visibility." Instructions for determining prevailing visibility in the United States are given in the Manual of Surface Observation used by the United States National Weather Services and the military services (Robinson, 1962b).

To determine the prevailing visibility under nonuniform conditions, the weather observer divides the horizon into several sectors of equal size in which the visibility is substantially uniform. The value reported as the prevailing visibility is the highest sector visibility which is equal to or less than the visibility in sectors that account for at least half of the horizon. In other words, the visibility around at least half the horizon is equal to or better than the prevailing visibility reported. For example, if the horizon were divided into four sectors and the respective visibilities were three, four, five, and eight miles (4.8, 6.4, 8.0 and 12.8 km), the prevailing visibility would be five miles (8 km). This has been the standard procedure in the weather services in the United States since January 1939. Prior to this time, it was the maximum visibility which could be observed around the horizon from the station (Robinson, 1962a).

These are some aspects about the determination of visibility measurements that require caution in their use for analysis. Because visibility is defined as the greatest distance at which objects can be seen, the measurement of visibility depends upon the objects present. In some localities the number and distribution of objects, or markers, may be unsatisfactory. Also, the erection of new markers may change the spectrum of reported visibilities. Moreover, as Robinson (1962b, p. 29) noted, "there is no fixed upper limit for reportable visibility. However, many stations do not have suitable markers at distances beyond 15 miles (24 km) and under such conditions the visibility over 15 miles is recorded at 15+. Such a procedure could cause confusion in preparing summaries of two stations with varying target horizons if data were carelessly lumped together." Another difficulty is in inconsistent observations among observers. This was mentioned as a problem by Holzworth (1961, p. 77) who said ". . . visibility observations are subjective estimates made by trained and experienced observers. These estimates are based on the ability to 'see' and it is known that such capacities are far from constant, either among different people or in the same person at different times." But despite these problems, for quantitative analysis, one must assume that the data given by the weather station are correct in observing and listing (Holzworth, 1961, p. 88).

Visibility is determined and recorded at specified hours by an observer looking around the horizon and noting whether he can identify known landmarks or lights. At Kuwait International Airport, these observations are made 24 times each day at the beginning of each hour. Most of the official records of the various national weather services specify an observation made with unaided eye of known landmarks or, at night, lights. As a guide for these "targets," weather stations typically have charts or photographs that show prominent objects and lights in various directions and list their distances from the station. Table 1 lists the near targets currently used at Kuwait International Airport Weather Station and shows their distances and directions (azimuths). Additional markers located at greater distances from the weather station, such as the oil tanks in Ahmadi (15 km to the south) and water tanks of Al-Sabah Hospital (12 km to the north-northwest), allow the observer to estimate high values of visibility from the sharpness with which distant objects stand out.

In Kuwait prevailing visibility is not reported (Safar, pers. comm., 1979). Kuwait International Airport Weather Station determines and records what might be termed "minimum visibility." This involves making observations in all directions and reporting the distance to the nearest observed target. For example, if the visibility in one direction is 1500 m, and in a second direction 1300 m, and in another one is 600 m, the horizontal visibility recorded would be 600 m.

Table 1. Visibility Objects for the Weather Station at Kuwait International Airport.[a]

Observe Stations	Azimuth	Distance in Meters
Substation G	190°	145
Substation U	160°	300
Wind Tower	90°	75
Hangar	120°	300
Control Tower St. 1	100°	550
Control Tower St. 11	220°	450
Deluge Pump	220°	180
Central Plant Bldg.	260°	480
Flood Light Tower No. 4 (South)	180°	560
Substation N	270°	1550
Main Substation	0°	1300
Doha Tank	0°	4000
Receiver Bldg.	200°	5250
Substation R	220°	1850
Mosque	75°	380

[a]Source: Kuwait, Meteorological Department, 1963-1978.

CHAPTER 2

REVIEW OF LITERATURE

During the past 25 years visibility and changes in visibility have been examined by a substantial number of research workers in several disciplines. Many of their studies have contributed useful ideas and methods of analysis that provide guidance for any contemporary attempt to investigate visibility.

One of the most extensive early studies of visibility trends relative to air pollution was carried out by Neiburger (1955) for downtown Los Angeles for the years 1933 through 1954. In his report, based upon observations taken by the Los Angeles Weather Bureau, he presented statistical evidence for changes in visibility in Los Angeles and used the trends he found to assess the effects of air pollution and the effectiveness of measures aimed at its control. He sorted his data according to wind direction and relative humidity and found that these meteorological factors, in conjunction with the prevailing lapse rate, exert a strong influence on visibility. In Neiburger's words (pp. 7-8),

> The concentration of particles arising from a source of given strength varies inversely with the volume into which these are dispersed. This dispersal volume depends on the wind speed across the source and the factors which control turbulent or eddy diffusion, the principal one of which is the vertical stability of the air, i.e., the temperature lapse rate (rate of decrease of temperature with height).
>
> Some substances tend to pick up water vapour at relative humidities substantially below 100 percent. Since particles of such hygroscopic substances, as well as nonhygroscopic particles, may be expected to be always present, the particle size

distribution, and therefore the visibility, depends on the relative humidity.

Holzworth and Mega (1960), also working in California, employed linear regression analysis to establish visibility trends. They tabulated the percent of visibility observations each month into four classes--0 to 10, 11 to 19, 20 to 30, and greater than 30 miles--and found that considering the frequency of visibility by class ranges, rather than by median or mean values, permitted detection of visibility changes appropriate for the precision of the standard observation data available. They concluded that slopes of regression lines through time show some evidence of deteriorating visibility in the Central Valley cities of Bakersfield and Sacramento. Their study was influential in establishing a standard approach to visibility analysis, although the trends indicated in the data were not as consistent and statistically significant as might have been expected.

Using a similar type of analysis, Robinson, Currie and James (1960), examined noon visibilities in downtown San Francisco for the years 1933 through 1956. They found great annual variation in visibility frequencies in various range classes, but no discernible long-term trend. Considering only cases of light wind and low relative humidity, their results suggested great difficulties in relating any long-term visibility trend to air pollution.

Holzworth (1961) summarized visibility observations with regard to effects of nearby air pollution sources. He also discussed the general effects of population and industrial growth on reducing the frequency of very good visibility conditions. To discriminate between natural fluctuations in visibility and those related to increased pollution, he suggested that visibility observations taken during times of rainfall, fog, strong winds, and high relative humidity be excluded from analysis. How this might be done was addressed in the following statement (p. 77):

> For precipitation this is straightforward. For fog it is much less so because many man-made pollutants are hygroscopic and may act as condensation nuclei in the formation of fog. Further the meteorological conditions favorable to fog formation are also conducive to poor dispersion of air pollutants. The usual procedure for eliminating cases of poor visibility due to [high humidity] is to select some relative humidity above which the visibility observations are neglected.

He illustrated the method of trend analysis suggested earlier (Holzworth and Mega, 1960) with data from the municipal airport at Salt Lake City, Utah. He considered only hourly daytime observations (8:00 a.m. to 5:00 p.m.), during periods with no precipitation and with relative humidities less than 90%. He divided visibility observations into a number of range classes, and tabulated the percent frequencies of occurrence in each of these classes for each year. He found in general a deterioration of visibility through time at Salt Lake City, and, with regard to the method, concluded (p. 78), "as a whole, the linear regression lines applied here, fitted by the method of least squares, depict the general trend in each range fairly well."

Elmer Robinson (1962a), in his book chapter entitled "The Effects of Air Pollution on Visibility," defined visibility and discussed methods of observation used at weather stations. He related visibility to weather elements (fog, haze, inversion height, wind speed, hygroscopic particles and relative humidity) and air quality standards. He commented on the general effects of air mass characteristics and inversion conditions on visibility. With regard to wind speed, he pointed out (p. 227) that "wind speed is another measure of the dilution potential of the atmosphere and it would be logical to expect better visibility when stronger winds provided better dilution." Here he ignored the potential effects of high winds on generating dust. Concerning hygroscopic particles and relative humidity, he pointed out (pp. 227-28) that "under high, but still not saturated, humidity conditions, hygroscopic particles pick up water and increase in size. As they increase in size, they become more effective in reducing visibility, particularly when humidity increases from 75% to 80%." He further discussed the calculation of visibility, applications of visibility observations, and the assessment of long-term visibility trends. In addition to these, he evaluated several previous studies of visibility trends, including Neiburger (1955), Robinson, Currie and James (1960) and Holzworth and Mega (1960).

Building on Holzworth's regression technique, Green and Battan (1967) performed a linear regression on the frequency of days with good visibility in Phoenix and Tucson, Arizona, with population as the independent variable. The data for Tucson showed a declining visibility over the period 1949 to 1965 and this had a strong negative correlation with total population. Phoenix experienced an apparent increase in visibility with population growth, but Green and Battan noted that the procedures used for estimating visibility in Phoenix were changed between 1957 and 1958, and that Phoenix visibility trends are highly questionable. They concluded that increasing population contributes to poor visibility, probably through increasing output of industrial pollutants, increased motor vehicle exhaust, and increased dust from land clearing, livestock, and agricultural activities.

Landsberg (1970) discussed the influence of man on microclimate and the difference in climate between city and its countryside, particularly in terms of air pollution. With regard to the influence of man-made and natural causes on visual range in big cities, he concluded (p. 584) that ". . . almost all climatic elements are affected by pollution--radiation, cloudiness, fog, visibility, and the atmospheric electric field." Peterson (1971), in his article on urban climate discussed the differences in visibility trends between urban and rural regions due to the increased concentrations of pollutants. He also discussed the effect of cities as sources of atmospheric particulates.

The Tucson Advisory Committee on Air Pollution (1971) studied visibility changes in Tucson during the period 1957 through 1970. It found that one of the main components of reduced visibility in Tucson is haze emanating from several sources, particularly copper smelters, motor vehicle exhaust, and airborne dust from unpaved roads. In an explanation of how different types of man-made pollutants cause visibility changes, this study pointed out that

> Reduction in visibility has several explanations. Primarily, it is caused by minute (.1-1 micron diameter) liquid or solid particles in the atmosphere. With the exception of nitrogen dioxide (which is brown in high concentrations) the gases in the atmosphere are invisible. However, when these gases are converted to liquid aerosols, by adsorption of water vapor or atmospheric reactions, they scatter light, resulting in reduced visibility. For example, sulfur dioxide as a gas is invisible, but when the humidity is sufficient, or when sulfur dioxide has been converted to sulfate in the presence of sufficient humidity, sulfurous or sulfuric acid results, producing a gray haze or smoke (p. 83).

> Motor vehicle emissions contribute to the visibility reduction by formation of liquid aerosols as a result of atmospheric interactions of hydrocarbons, sunlight, and nitrogen dioxide. It could also increase the amount of solid particulate in the air by stirring up surface dust from unpaved roads and parking areas (p. 82).

Greenwood and Edwards (1973) discussed origins of air pollution and clarified them into these general processes: attrition, vaporization, and combustion. Attrition refers to foreign matter added to the air through any form of friction--carbon from automobile tires, for instance, or asbestos from brake linings. Industrial activities such as blasting, grinding, and cutting are also prime friction-type contributors. Vaporization (evaporation) is the process by which liquids become gases and diffuse in the atmosphere. Improper storage and handling, together with inefficient energy conversion techniques contribute to this process. Combustion, the greatest contributor, generates both gaseous and particulate impurities, and the automobile engine is a particularly important source.

In a study of visibility in Fresno, California, Hays (1974) found an overall decline during the period from 1939 through 1971. He suggested that the "rather dramatic drop in visibility is probably related to industrial activity and automobile traffic in the San Joaquin Valley and the San Francisco Bay area" (p. 60). "Furthermore, any increases in cultivation of valley land could contribute to increases in both dust and humidity" (p. 60).

Terjung (1974, p. 112) agreed with Landsberg that "horizontally, urban haze interferes with visibility and can result in reductions of 80-90 percent." He also mentioned that the formation of water droplets around hygroscopic nuclei, which are plentiful in urban air, could increase in incidence of formation of fog in cities. Leighton (1973) mentioned that visibility reduction is usually the first symptom of air pollution to be recognized. He also stated that ". . . 97% of the population of California lives in areas where visibility has deteriorated" (p. 234).

Truszkowsky and Wieden (1979) analyzed fog and visibility changes in the San Joaquin Valley, California from 1939 through 1978. They used curvelinear regression techniques (third degree) to describe variations in the occurrence of "dense fog" at Fresno which increased until about 1969 and subsequently decreased. Visibility observations at Bakersfield followed a consistent pattern, decreasing to 1969 and showing improvement thereafter. They explained these changes as functions of population growth, industrial activities, and developing environmental awareness and legislation.

In Kuwait, Al-Bana (1975) is an Arab geographer who has described environmental pollution as an aspect of applied geography. He stressed the interest of geography and geographers in environmental pollution, described major natural and man-made sources in Kuwait, and discussed the consequences of pollution for life and atmospheric processes. He also discussed the general effects of pollution on reducing visibility, particularly in urban and industrial areas, due to increased amounts of industrial smoke, fumes, and dust, and offered examples from several other countries. Hijazi (1975) examined the meteorological factors affecting air pollution in Kuwait and surrounding areas, and dealt particularly with sand and dust storms. However, he did not deal with visibility observations.

Summary

The literature described above presents valuable information on the importance of human activities in controlling visibility in many different areas. In addition to specific conclusions, these studies have utilized procedures useful for investigating visibility changes. My procedures incorporate many of the methods and conclusions of previous studies in their selection of variables, attempts to detect trends through time, and attempts to relate changes to possible causes.

CHAPTER 3

METHODS OF ANALYSIS

The analytical procedure employed in this study may be grouped according to three fundamental issues considered. These involve 1) documenting the recent history of visibility in Kuwait, 2) establishing relationships between weather conditions and visibility observations, and 3) assessing the role of human activities in controlling visibility.

Visibility Conditions since 1963

The initial question is essentially descriptive: "What has happened to visibility in Kuwait since 1963?" My attempt to provide an answer involves five steps: 1) consideration of available visibility data, 2) selection and calculation of representative quantitative variables, 3) graphic presentation of changes since 1963, 4) validation of changes with regard to possible randomness, and 5) identification of possible meaningful trends or fluctuations.

Visibility data were taken directly from the unpublished "Daily Register of Kuwait International Airport Weather Station, Climatological Section" (Kuwait, Meteorological Department, 1963-1978). This register contains a record of hourly observations made since 1963 and represents the longest continuous sequence of visibility data for Kuwait.

Observations made at 6:00 a.m. and 12:00 noon form the basis for this investigation. The selection of 6:00 a.m. is easily justified, in that this hour approximates the coolest hour of the day and thus is probably typified by shallow temperature inversions and minimal turbulence. Many other weather observations are also made at this hour. Several studies of visibility undertaken elsewhere have used early morning readings of 5:00 and 6:00 a.m. (Neiburger, 1955; and Holzworth and Mega, 1960), which have the additional advantage of illustrating prevailing conditions at a low point in daily cycles of human activity.

The use of noon observations is less than optimal. Reading in the mid- or late-afternoon when temperature lapse rates are usually steepest, turbulence greatest, and contributions of air pollutants from both natural and human sources potentially greatest, would be preferable. However, other studies also used this reading (Neiburger, 1955), and also most of the afternoon and late-afternoon summary of visibility observations in Kuwait are not available in a continuous sequence for use in this study.

For analytical purposes, both 6:00 a.m. and noon visibility observations were sorted into four categories: 0-3 km ("poor visibility"), 4-6 km ("low visibility"), 7-9 km ("intermediate visibility"), and 10+ km ("high visibility"). The choice of four categories is somewhat arbitrary, although it is important to differentiate between restricted and long-range visibility, and there is no obvious quantitative limit between these two general classes. Unfortunately, the lower limit for the "high" category could not be set at a value greater than 10 kilometers because observations greater than this value were often reported simply as "10 kilometers," particularly after 1968, because the Kuwait Civil Aviation authorities were unconcerned with precise long range readings. The number of observations in each visibility range at each hour are summed to yield the total number of days each year with poor, low, intermediate, and high visibility, at both 6:00 a.m. and noon. These values are presented on simple graphs to illustrate changing visibility from 1963 through 1978. Thus, "deteriorating" visibility would be indicated by reduced frequency of observations (days) in the 10+ km (high) category and increased frequency in the 0-3 km, 4-6 km, and/or 7-9 km categories. "Improving" visibility would be indicated by increased frequency of observations (days) in the 10+ km (high) category and reduced frequency in the 0-3 km, 4-6 km, and/or 7-9 km categories.

Establishing the validity of perturbations, fluctuations, cycles or consistent trends contained in these data is the classic problem of time sequence analysis. One approach is provided by the so-called "runs test." To quote Cooke and Reeves (1976, pp. 146-47):

> The runs test is based on the argument that most sets of time-dependent data will contain fewer sequences of consecutive values above or below the median of these data than a set which is randomly distributed in time. With the existence of cycles and/or trends there would be a tendency towards longer runs of values above the median and of values below the median, and thus a tendency for the total observed numbers of runs, to be fewer than the number expected if the series were entirely random.
>
> . . . The test is not able to differentiate cyclic and secular tendencies; this is normally left to visual interpretation. The value of the runs test lies in its ability to limit quickly subjective speculation about a set of data and to indicate whether or not effort should be made with more sophisticated and time consuming searches for trends.

This test is applied to data for all four visibility categories.

Finally, visibility changes over the period of record for each range category are summarized by fitting a least-squares equation to the data. This is illustrated by lines drawn on the graphs. Consistent trends in the various categories would be indicated by appropriate slopes and good fits. However, the difficulties of interpreting these trends by means of standard regression quotients and coefficients are well known.

Weather Conditions and Visibility

The second question to be answered is "To what extent do weather conditions influence visibility?" My objective is to identify weather conditions that restrict visibility so that observations made when these prevail can be omitted from the visibility record. The resulting weather-adjusted record provides a basis for investigating possible human influences on visibility. My procedures involve 1) identifying appropriate elements of weather for which reliable data exist, 2) assessing their relationship to visibility observations, and 3) retabulation of visibility records to exclude observations made during adverse conditions.

The studies discussed in Chapter 2 list several weather conditions that obscure visibility. Independent observations on some of these were taken at 6:00 a.m. and 12:00 noon at Kuwait International Airport, including wind speed, fog, mist, and relative humidity. Winds of 16 knots or greater at Kuwait International Airport tend to raise dust (M. Safar, pers. comm., 1979), and I decided to adopt this value as critical. Observers' notations in the record that mention the presence of moderate fog, thick fog, moderate mist and slight mist were also utilized. Relative humidity observations exceeding 75% were adopted for analysis. In addition, any day on which rainfall occurred was considered.

Using regression analysis, the percent of visibility observations each month in each range class was correlated with the percent of monthly observations of each potentially restrictive weather condition. Multiple regressions were performed to provide a rough estimate of the extent to which all of these adverse weather conditions acting together relate to visibility in each of the range classes.

For a variety of reasons, three potentially meaningful weather elements were not considered. Temperature inversion data, although perhaps the most important single element influencing visibility, is not regularly collected at 6:00 a.m. and 12:00 noon. Observers' notes concerning "dust," "sand storms," and "haze" could not be employed, because the definitions of these phenomena used by the Kuwait Directorate General of Civil Aviation (1972) rely on visibility criteria and cannot be evaluated independently. Wind direction data are available and might be valuable, but at the level of analysis used in this study, it is difficult to conceive how to use directional information adequately.

Strong winds, fog, mist, high humidity, and rainfall do relate to poor and high visibility observations, although some of these weather variables are more closely associated than others. These conditions occurred during about 25% of the observations contained in the 1963-78 visibility record (23% at 6:00 a.m. and 28% at 12:00 noon). Eliminating visibility observations taken during adverse weather produces adjusted records of reduced length--4,497 days at 6:00 a.m. and 4,161 days at 12:00 noon--compared to original records of 5,844 days.

Visibility fluctuations remaining in these weather-adjusted records should represent human influences on visibility somewhat more clearly than unadjusted observations. Trends and fluctuations in weather adjusted records are described and analyzed in much the same fashion as described above for unadjusted records.

Assessing Human Influences

The central question asked here is "What is the role of human activities in regulating visibility?" Two different approaches are used to attempt to supply an answer.

First, visibility conditions as represented by weather-adjusted records for 6:00 a.m. and 12:00 noon are analyzed for differences that might exist between weekdays (Saturday through Thursdays), when most human activities are in progress, and the weekends (Fridays), the normal working holiday in Kuwait. A simple, non-parametric test of association between dichotomous variables, Yule's Q, is used to examine the relationship (Davidson, 1976). If human activity significantly affects visibility, one would expect that visibility on weekends would be noticeably better on Fridays than on weekdays. That is, the relative frequency of Fridays with visibility of 10 kilometers or more should be higher than the frequency of weekdays with high (10 km+) visibility. Conversely, the relative frequency of observations of 3 kilometers or less should be low on Fridays compared to weekdays.

Second, in an attempt to determine what kinds of human activities relate most closely to reduction of visibility, simple regression analyses were applied to annual figures for visibility in two range classes (0-3 km and 10+ km) and an annual figure for 23 different measures of human activity. These measures are (Kuwait Central Statistical Office, 1963-1978).

1. Total population by year,
2. Production of salt and chlorine (tons),
3. Production of hydrochloric acid (gallons),
4. Production of fertilizer and chemical products (metric tons),
5. Production of building materials by the National Industrial Company,
6. Production of hydrated lime building materials (tons),
7. Production of asbestos pipe and sheet (tons),
8. Production of concrete slabs and blocks (M^2),
9. Production of kerbstone, concrete pipe and shafts (M^2),
10. Sales of the Kuwait Aviation Fueling Company (barrels),
11. Aircraft movement at the Kuwait International Airport,
12. Gasoline sales in Kuwait (10^6 liters),
13. Number of vehicles in use,
14. Area of paved road (M^2),
15. Production of Kuwaiti refineries (barrels),
16. Amount of natural gas consumed in Kuwait (10^6 ft^3),
17. Amount of wasted and flared natural gas (10^6 ft^3),
18. Construction permits by area (M^2),
19. Number of demolition permits,
20. Area of agricultural holdings (dounins),
21. Total number of livestock (cattle, sheep, goats),
22. Production of the Kuwait Cement Company (tons), and
23. Production of ready-mixed concrete (M^3).

They may not be the best possible measurement of human activities, but they were the only long-period statistical records that could be obtained. It is hoped that correlations between visibility and these factors can provide at least a general indication of the human effects. Because most of the data were given in yearly totals, the testing of all but two of the factors involved simple regression with total annual.

In addition, two variables are available by month: production of Kuwait's refineries and aircraft movement at Kuwait International Airport. The association between these two factors and the number of days of high and low visibility in each month is also examined.

CHAPTER 4

DISCUSSION--VISIBILITY SINCE 1963

Early morning (6:00 a.m.) and noon visibility observations in Kuwait since 1963 exhibit similar patterns: conditions were relatively "good" for the first few years of record, 1963-1965, they deteriorated notably during the following three years, 1966-1968, and then improved to a level nearly as good as in the initial years. Since 1975 there has been a slight, slow deterioration.

Morning Visibility Conditions

Figure 6 documents visibility fluctuations at 6:00 a.m. for each of the four range classes. "High visibility" (10 kilometers and greater) is the typical conditions on most mornings and has ranged between 160 observations in 1968 and 337 observations in 1963. The first three years of record (1963-65) contain a relatively high frequency of high visibility observations, but the following sequence of years contain the three lowest frequencies of the entire record. From 1969 through 1978 there appears to be little significant variation.

"Poor visibility" observations (less than 4 kilometers) are relatively rare and have been reported on between six and 33 mornings during each of the years since 1963. During the mid-1960s and mid-1970s there were very few mornings with poor visibility. The late 1960s contained a notably higher frequency, and since 1975 the number has increased steadily.

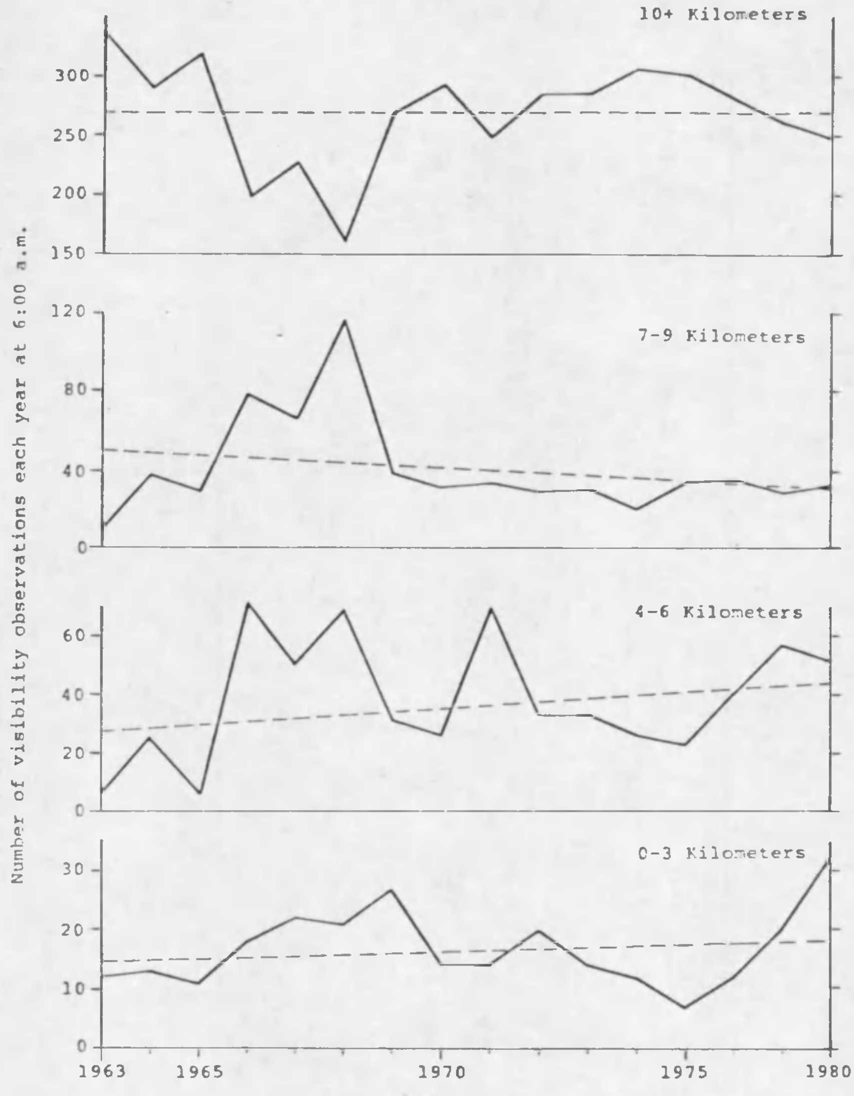

Figure 6. Visibility at 6:00 a.m. at Kuwait International Airport (not adjusted for weather conditions).

The frequency of mornings with intermediate visibility (4-6 and 7-9 kilometers) shows varying patterns. The plot for 7-9 kilometers is almost a perfect complement for the 10+ kilometer plot, with high frequencies in this range class in 1966, 1967, and 1968 and little fluctuation since then. Observations in the 4-6 kilometers range are irregular through time, but tend to show aspects of both lower and higher range classes.

Whether or not these fluctuations represent anything other than the random interaction (operation) of phenomena influencing visibility is a crucial question. Patterns shown by the graphs are certainly not simple.

Results from the run tests (Table 2) provide some encouragement. The sequence of poor visibility (0-3 kilometers) deviates significantly (.05 level) from randomness, although three of the observations occupy the median value. The sequence of high visibility observations also deviates from what one might expect from a random sequence, but the probability is only .061.

It is doubtful that long-period trends account for the non-random component of these plots. Linear least-squares lines are fitted to each of the graphs in Figure 6. They show little deviation from the horizontal and certainly represent nothing of statistical significance.

If there are meaningful trends, their period is short and easily detectable only through subjective manipulation of the record. The most discernable "trends" would be produced by arbitrary subdivision in 1968, with deterioration in previous years and improvement thereafter.

Table 2. Results of Runs Test.

Visibility Range	Time	Expected # of Runs μu	Observed # of Runs U	Probability
Poor				
0-3 km	6:00 a.m.	7.46	4	.021[a]
High				
10+ km	6:00 a.m.	9	6	.061[b]
Low				
4-6 km	6:00 a.m.	8	6	.134
Intermediate				
7-9 km	6:00 a.m.	9	9	.500
Poor				
0-3 km	12:00 noon	9	6	.061[b]
High				
10+ km	12:00 noon	9	6	.061[b]
Low				
4-6 km	12:00 noon	9	4	.005[c]
Intermediate				
7-9 km	12:00 noon	9	5	.019[a]
Restricted				
0-9 km	6:00 a.m.	9	6	.061[b]
0-9 km	12:00 noon	9	6	.061[b]

[a]Significant at the .05 level.

[b]Significant at the .10 level.

[c]Significant at the .01 level.

Noon Visibility Conditions

Figure 7 illustrates the visibility at 12:00 noon. Overall, the pattern of fluctuations is very similar to that of the 6:00 a.m. data. High visibility at noon differs from 6:00 a.m. mainly in the lower number of days of recorded observations. This difference can be seen in the range between 145 observations in 1969 and 293 observations in 1965. As in the 6:00 a.m. record, the first three years (1963 to 1965) have a high frequency of high visibility. After 1965 visibility deteriorated sharply until 1968 when an upward trend began and continued until the mid-1970s.

Poor visibility observations were both more common and more erratic at noon than at 6:00 a.m. From a high frequency of poor visibility in 1963 and 1964 the number declined to almost half as many days in 1965. Following that, there was an increase to a high level of poor visibility from 1967 to 1971. From 1971 to 1976 there is a period of decrease in frequency of low visibility days. In the late 1970s the frequency of poor visibility observations increased again.

Middle range classes (4-6 and 7-9 km) reflect changes in the poor and high visibility record. As at 6:00 a.m. the 7-9 km record is strongly complementary to the 10+ km record. In general, the 4-6 km pattern is similar to the 0-3 km record.

The runs test (Table 2) shows varying levels of significance for fluctuations in all visibility ranges at this hour. Both poor (0-3 km) visibility and high (10+ km) visibility show a probability of only .06 that they are random sequences. The probability that fluctuations in

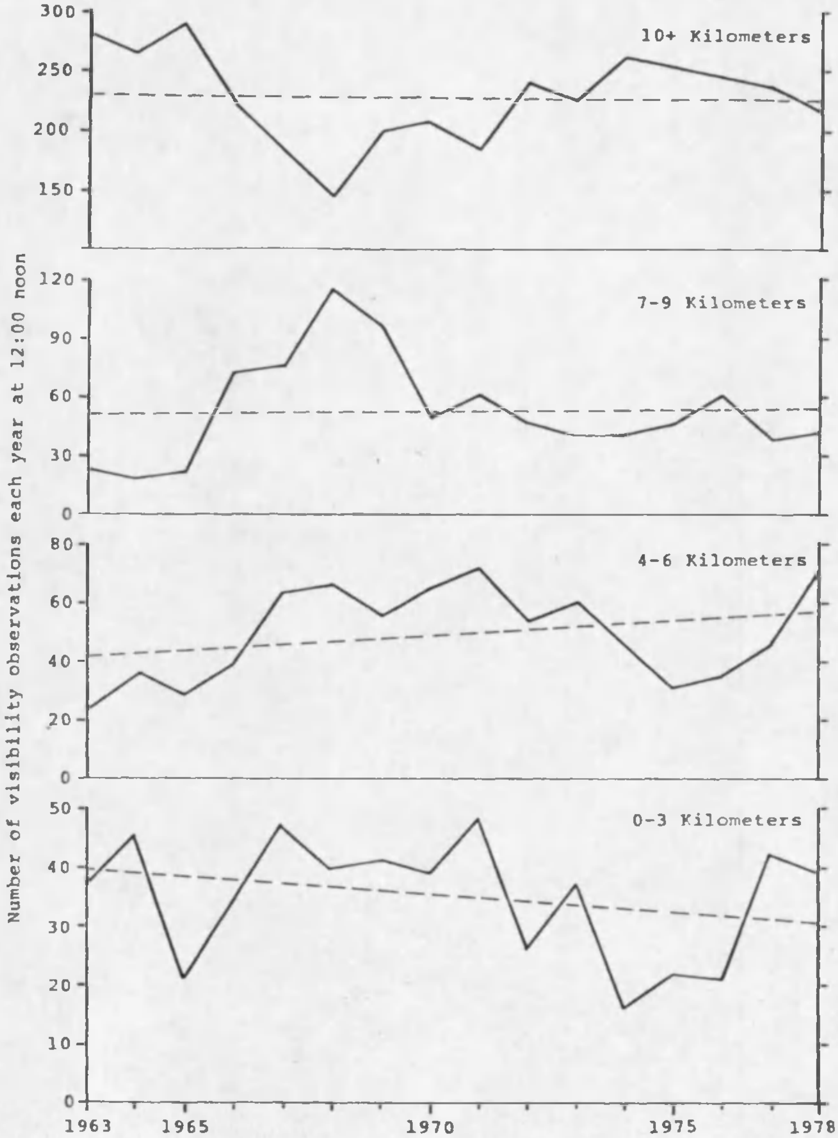

Figure 7. Visibility at 12:00 Noon at Kuwait International Airport (not adjusted for weather conditions).

the 4-6 km class are random is only .005 and that for the 7-9 km category is .019.

In general, the least squares lines show no meaningful long-term trends. As for the 6:00 a.m. data there appears to be a sharp decline in visibility before 1968 and a subsequent improvement, at least until about 1975.

Summary

The general patterns at both 6:00 a.m. and 12:00 noon show a similar decline in visibility before 1968 and some increase thereafter. It should also be noted that the number of days of high visibility at noon is somewhat less than at 6:00 a.m. Similarly, the number of days of poor visibility is greater at noon than at 6:00 a.m.

CHAPTER 5

WEATHER CONDITIONS AND VISIBILITY

Fluctuations in visibility between 1963 and 1978 are complex and difficult to explain. There is little clear indication in the graphs of Chapter 4 that man-made pollution or any other single factor is directly controlling visibility conditions as recorded at Kuwait International Airport.

Long-term trends appear absent. However, it is possible that variation in weather conditions has acted through time to obscure simple trends or other patterns. Certain weather conditions, e.g., fog, obviously influence visibility. It is conceivable that the frequency of occurrence of these conditions may have changed enough over the period of record to influence observations. In this chapter, the relationship between several weather conditions and visibility is examined and used as the basis for adjusting the record of visibility observations.

Table 3 lists simple coefficients of correlation between seven weather elements and visibility. Four of the weather variables--thick fog, moderate fog, moderate mist, and high windspeed--relate closely to visibility. High frequencies of these conditions produce high frequencies of poor visibility (0-3 km) observations and are negatively related to the number of observations in the 10+ km range class. The relative humidity variable shows some inconsistency, as does that for rainy days. Slight mist exhibits little if any relationship to visibility.

Table 3. Coefficients of Correlation between Monthly Frequencies of Seven Weather Conditions and Visibility in Four Range Classes (N = 192 months of observations).

Visibility range	6:00 a.m.	12:00 noon
Thick fog		
0-3 km	.408	.084
4-6 km	-.072	.005
7-9 km	-.100	-.088
10+ km	-.011	-.002
Moderate fog		
0-3 km	.238	-.079
4-6 km	-.076	-.054
7-9 km	-.052	-.106
10+ km	.007	.103
Moderate mist		
0-3 km	.417	-.095
4-6 km	.173	.098
7-9 km	-.056	-.003
10+ km	-.168	-.425
Slight mist		
0-3 km	.049	-.023
4-6 km	.071	.003
7-9 km	.015	-.047
10+ km	-.056	.017
Relative humidity (> 75%)		
0-3 km	.147	-.142
4-6 km	-.199	.032
7-9 km	-.154	.045
10+ km	.149	.002
Rainy days		
0-3 km	.088	-.228
4-6 km	-.010	-.028
7-9 km	-.019	-.019
10+ km	.031	.025
Windspeed (≥ 16 knots)		
0-3 km	.164	.670
4-6 km	.057	.358
7-9 km	.099	.118
10+ km	-.124	-.425

Individual Weather Variables

Thick fog is obviously most significant in the morning with the strongest association at 0-3 km (r = .408). In all of the cases greater than 6 km it shows slight negative correlation, although the coefficients are very close to zero. Moderate fog is also most strongly correlated with poor visibility at 6:00 a.m. (r = .238). The positive correlation with high visibility at noon (r = .103) and the negative correlations at other ranges at noon are confusing, but probably result from the very rare occurrences of fog at this hour.

Moderate mist shows strong and predictable relationships with visibility in all categories except the 0-3 km range at noon, and is perhaps the "best" of the weather variables employed. In contrast, the slight mist variable seems unrelated to visibility observations.

The correlation coefficients for high relative humidity (more than 75%) are strongest at 6:00 a.m., although at noon it has a negative association with poor visibility (0-3 km). At 6:00 a.m. there appears to be an indication of a very complex relationship between high humidity and the various ranges of visibility. Both poor and high visibilities show some positive correlation while the mid-ranges show negative correlation. This may be due to the presence of fog and mist serving to reduce visibility in some cases and rain clearing the air of particulate matter in other cases. Both these situations would involve high humidity, but more sophisticated data and analysis are needed to clarify this relationship.

Rainy days have a slight effect on visibility in all cases except poor visibility at noon (r = -.228).

High winds (16 knots and over) have the greatest effect at noon. It has a strong positive correlation with poor visibility (r = .670); it also shows strong correlation with low visibility (4-6 km). It also has a sizeable negative correlation (r = -.425) with high visibility (10+ km). At 6:00 a.m. the associations are similar but not as strong.

Combined Effect of Weather Conditions on Visibility

Table 4 lists some of the results of multiple regression analysis between all seven weather variables and visibility in the four range classes at 6:00 a.m. and noon. Because none of the variables are normalized and most represent highly skewed distributions, probability statements and inferences are inappropriate. Nevertheless, the coefficients of correlation and the squares of these values offer strong indications concerning association between the group of weather variables and visibility.

For the 7-9 km visibility range, only four of the weather variables appear to influence visibility. At 6:00 a.m., these are relative humidity, slight mist, rainy days and high winds. At 12:00 noon these include high wind, rainy days, thick fog, and moderate fog. For all other range classes and hours, each of the seven variables appears to exert some influences on the regressions.

From Table 4 it appears that the combined weather conditions are most important in their influence on poor visibility (0-3 im) ranges at both 6:00 a.m. and 12:00 noon. This is displayed in the relatively large coefficients of multiple correlation 0.683 at 12:00 noon and 0.651 at 6:00 a.m. For high ranges (10+ km) of visibility, there is also a

Table 4. Multiple Regression Coefficients (R and R^2) between Weather Conditions and Visibility Range.

Visibility Range	Morning Hour (6:00 a.m.) R	R^2	Noon Hour (12:00 noon) R	R^2
0-3 km	0.651	.423	0.683	.467
4-6 km	0.361	.130	0.407	.166
7-9 km	0.234	.055	0.224	.050
10+ km	0.342	.117	0.454	.207

moderately high coefficient of 0.454 at 12:00 noon and a slightly lower R value of 0.342 at 6:00 a.m. The 4-6 km visibility range shows a somewhat similar pattern to that of the 10+ km range, with a multiple correlation coefficient of 0.407 at 12:00 noon and slightly smaller value of 0.361 at 6:00 a.m. The 7-9 km visibility range displays weaker correlation than the other ranges; for 12:00 noon it is 0.224 and for 6:00 a.m. it is 0.234. The 7-9 km range may not show as clear relationship with weather variables because of its intermediate position. In terms of the weather conditions, influences of severe weather are more likely to reduce visibility to low levels, while absence of severe weather conditions will allow observations beyond 10 km.

In all ranges but 7-9 km, slightly higher relationships appear to exist between weather variables and visibility at 12:00 noon than at 6:00 a.m.

The Weather Adjusted Record

Weather adjusted trends were constructed for the extreme visibility ranges of 0-3 and 10+ km at both 6:00 a.m. and 12:00 noon, by eliminating all observations made during times of heavy fog, moderate mist, slight mist, high humidity, high wind and on days with recorded rainfall. Elimination of significant weather conditions appears to create more fluctuations in the record, but generally speaking, there is not much difference between the weather adjusted and nonadjusted trends (Figures 8 and 9).

Figure 8 presents visibility fluctuations at 6:00 a.m. for each of the two range classes. As with the nonadjusted record, high visibility (10+ km) observations are infrequent during 1966, 1967 and 1968. After this period, however, the adjusted record seems to contain substantially more fluctuations and lacks the downward trend starting about 1972.

In the poor visibility (0-3 km) record, elimination of weather variables reduces the number of low visibility days by about half, but the pattern through time is remarkably similar to the nonadjusted record. The single peak of high numbers of low visibility days in 1969 found in the unadjusted record is converted to a "plateau" from 1966 to 1969. The sharp increase in number of poor visibility observations in the late 1970s is apparent in both records.

At 12:00 noon (Figure 9), the adjusted record is similar to the unadjusted for high visibility observations, except for slightly increased fluctuation in the 1970s. The long-term downward trend is also accentuated, as shown by the least squares line plotted on the graph.

For 0-3 km, the weather adjusted trend does show some notable differences. The lowest observation is shifted from 1974 to 1975 and several other "peaks" and "valleys" are either shifted or removed. The

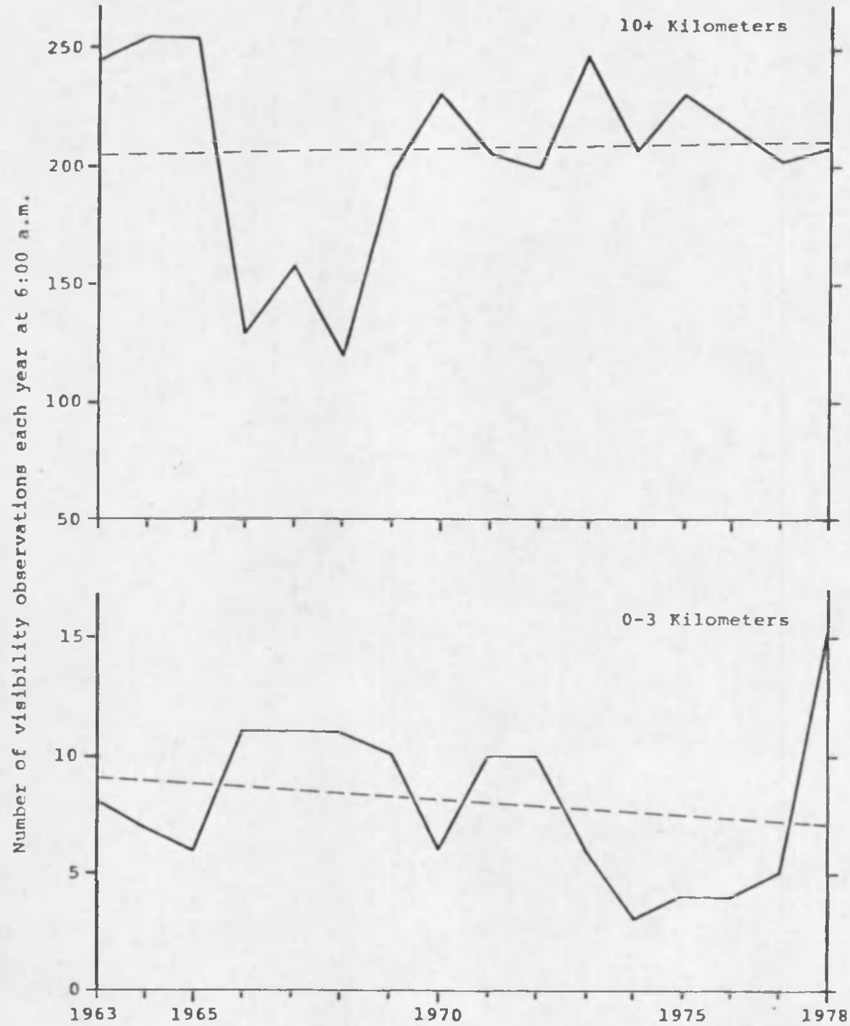

Figure 8. Weather-adjusted Visibility at 6:00 a.m. at Kuwait International Airport.

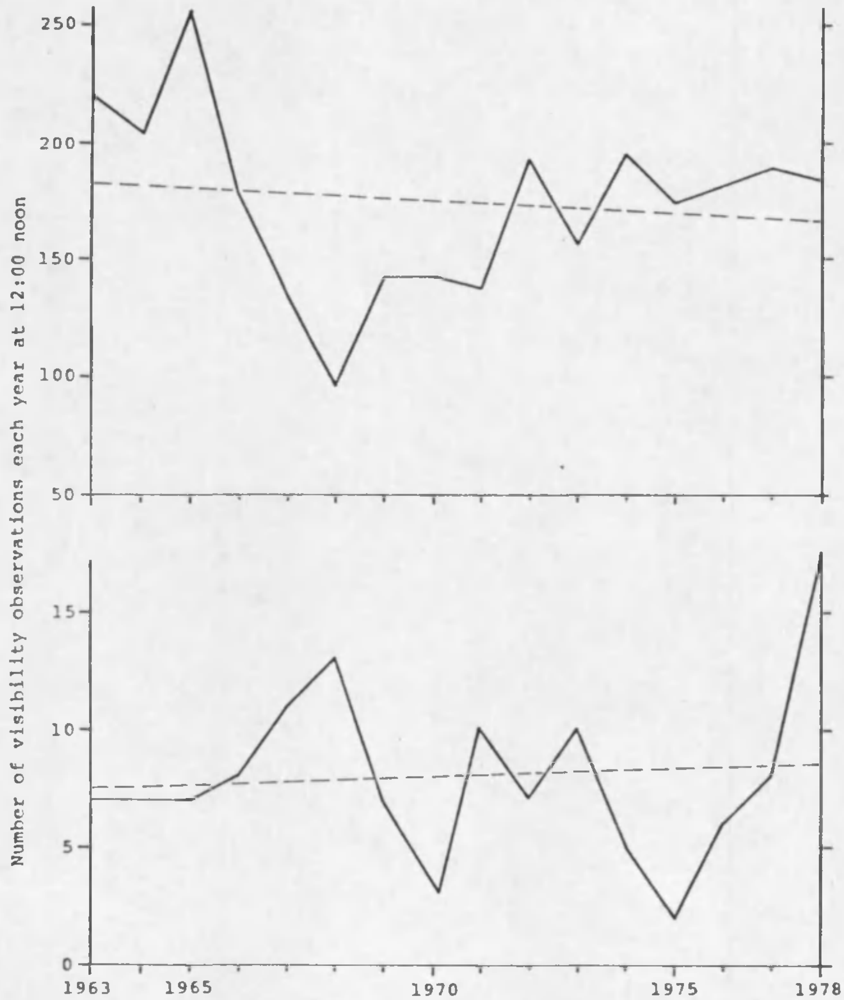

Figure 9. Weather-adjusted Visibility at 12:00 Noon at Kuwait International Airport.

long-range trend becomes positive rather than negative and a notable increase in poor visibility observations becomes apparent in the late 1970s. Nevertheless, whether these adjusted data actually show a real deterioration of visibility is still subject to debate.

CHAPTER 6

HUMAN INFLUENCES

There is a definite but weak association between levels of human activity and visibility. Long range visibility is significantly better on Friday (the weekend) than on other working days of the week. However, the influence of increasing human activity during the 1960s and 1970s is not clearly associated with visibility. The plots of weather adjusted values in Chapter 5 provide only modest suggestions. The single factors treated in this chapter show no significant associations with visibility and shed very little light on the nature of human controls.

Visibility on Fridays and Weekdays

Table 5 shows no difference between visibility on weekdays and Fridays for the poor visibility ranges at both 6:00 a.m. and 12:00 noon, in both adjusted and unadjusted records. For the unadjusted record at 6:00 a.m. the proportion of Fridays with poor visibility is the same as the proportion of weekdays with poor visibility, 4.7% of all observations in each category. At 12:00 noon on Fridays poor visibility has occurred 9.4% of the time, compared to 10.0% for weekdays. Similarly, the adjusted record shows proportions at 6:00 a.m. of .025 for Fridays and .026 the the weekdays, and at 12:00 noon it shows .037 for Fridays and .027 for the weekdays. These results combined with the information from the regression analyses of the weather conditions, seem to indicate that poor visibility (in the 0-3 km range class) is mainly a function

Table 5. Low Visibility (0-3 km) on Fridays vs. Other Days of the Week, 1963-1978.

Visibility Range	Friday Observations	Weekday Observations	Totals	Yule's Q[a]
0-3 km	39	235	274	
> 3 km	795	4775	5570	
Total	834	5010	5844	-.001
At 12:00 noon, the unadjusted record:				
0-3 km	78	501	579	
> 3 km	756	4509	5265	
Total	834	5010	5844	-.037
At 6:00 a.m., adjusted record:				
0-3 km	16	101	117	
> 3 km	617	3748	4365	
Totals	633	3849	4482	-.022
At 12:00 noon, adjusted record:				
0-3 km	21	98	119	
> 3 km	549	3476	4025	
Totals	570	3574	4144	+.151

[a](no significant Q values at the .05 level).

of weather conditions including fog, mist, and probably dust raised by strong winds.

On the high ranges of visibility, however, human influences appear to have a strong effect. As indicated by Table 6, there are very significant differences between Fridays and weekdays for visibility at 10 km and greater. For the unadjusted record at 6:00 a.m., the proportion of Fridays with visibility greater than 9 km is .782, compared with .730 for weekdays. The unadjusted record at 12:00 noon shows the proportion of 10 km observations to be .682 for Fridays and .618 for weekdays. A similar pattern appears in the adjusted record of .782 for Fridays and .723 for the weekdays at 6:00 a.m. and .732 for Fridays and .658 for weekdays at 12:00 noon.

In all cases in both adjusted and unadjusted records, high visibility is more likely to occur on Fridays when normal human activities are not in operation. This suggests very strongly that human influences are most likely to be seen in their effects on high levels of visibility.

From Chapter 5, the pattern of visibility trends through time do not clearly indicate a deterioration that can be attributed to the rapidly increasing population and human activity in Kuwait during the past two decades. A single indication of influence may be seen in the differences between the nonadjusted and the adjusted trend at 6:00 a.m. before the beginning of the day's economic activities. The weather adjusted trends suggest a slight decrease in the number of days of poor visibility and an increase in the number of days in the high visibility range. This can be compared with an increasing trend in the number of days of poor visibility and in the more or less steady level of high

Table 6. High Visibility (10+ km) on Fridays vs. Other Days of the Week, 1963-1978.

Visibility Range	Friday Observations	Weekday Observations	Totals	Yule's Q
At 6:00 a.m., unadjusted record:				
0-9 km	182	1351	1533	
10+ km	652	3659	4311	
Total	834	5010	5844	+.140[a]
At 12:00 noon, unadjusted record:				
0-9 km	265	1913	2178	
10+ km	569	3097	3666	
Total	834	5010	5844	+.140[a]
At 6:00 a.m., adjusted record:				
0-9 km	138	1065	1203	
10+ km	495	2784	3279	
Total	633	3849	4482	+.157[a]
At 12:00 noon, adjusted record:				
0-9 km	153	1223	1376	
10+ km	417	2351	2768	
Total	570	3574	4144	+.173[b]

[a]Significant at the .001 level.

[b]Significant at the .01 level.

visibility days in the unadjusted record. The 12:00 noon data similarly show some indication of effects of human activity. The weather adjusted record shows a slight increase in the number of days in the high visibility range. These adjusted trends can be contrasted with the unadjusted trends of decreasing number of days of poor visibility and a lower level of steady trend for high visibility. This slight change in the adjusted trend provides some evidence for the idea that human influences are affecting visibility. However, extreme year to year fluctuations provide only a subtle indication of trends, and do not allow for conclusive statements.

The strongest evidence for the influence of human activities on visibility appears in the significant differences between Fridays and weekdays evaluated by the Yule's Q tests. This evidence is also supported by the slight trends of deteriorating visibility shown in the adjusted record of observations at noon.

Visibility and Specific Human Activities

My search for specific human controls of visibility was not very successful. The simple regressions of annual production of various activities against total days of poor and high visibilities at 12:00 did not suggest very strong relationships between any of these variables and visibility.

Table 7 shows correlation coefficients for regressions between human activity variables and observations of poor visibility. Only production of natural gas, production of salt and chlorine, production of refineries, and production of the Kuwait Cement Company produced

Table 7. Coefficients of Correlation between Annual Measures of Human Activity and Poor Visibility Observations at 12:00 Noon.

Human Activity Variables	r	Probability
Total population by year	.106	.348
Production of salt and chlorine	-.412	.063[a]
Production of hydrochloric acid	-.205	.232
Production of fertilizer and chemical products	-.289	.149
Production of building materials by NIC	-.122	.332
Production of hydrated lime building material	.011	.483
Production of asbestos pipe and sheets	-.338	.129
Production of concrete slabs, block	-.266	.161
Production of kerbstone, concrete pipes and shafts	-.250	.184
Sales of Kuwait Aviation Fueling Company	-.093	.413
Aircraft Movement at Kuwait International Airport	-.073	.397
Gasoline Sales in Kuwait	.245	.171
Number of vehicles in use	-.270	.165
Area of paved road	-.236	.256
Production of refineries in Kuwait	-.367	.089[a]
Amount of natural gas consumed in Kuwait	-.543	.018[b]
Amount of wasted and flared natural gas	-.069	.403
Construction permits by area	-.121	.341
Number of demolition permits	-.268	.177
Area of agricultural holdings	-.499	.104
Total number of livestock (cattle, sheep, goats)	-.266	.242
Production of Kuwait Cement Company	-.427	.056[a]
Production of ready-mixed concrete	.261	.183

[a]Significant at the < .10 level.

[b]Significant at the < .05 level.

coefficients significant at the .10 level. Of these, only amount of natural gas consumed in Kuwait indicated a level of significance below .05. In all cases, these coefficients of correlation are negative, and thus opposite in sign to anticipated relationships. If these human activity variables were increasing the frequency of poor visibility, one would expect positive coefficients.

Table 8 indicates correlation coefficients and significance levels of regressions with high visibility observations. Only sales of the Kuwait Aviation Fueling Company, production of refineries in Kuwait, and total number of livestock produced coefficients significant at the .10 level. Once again, however, these relationships are opposite in sign to what one would expect. In all three cases the higher the production, the more frequent are days with high visibility.

Monthly data were available to me for only two variables: national refinery production and aircraft movement at Kuwait International Airport. As shown in Tables 9 and 10, neither of these variables show notable relationships with either poor or high visibility at 12:00 noon over the period of record.

Table 8. Coefficients of Correlation between Annual Measures of Human Activity and High Visibility Observations at 12:00 Noon.

Human Activity Variables	r	Probability
Total population by year	-.105	.349
Production of salt and chlorine	.035	.451
Production of hydrochloric acid	-.096	.367
Production of fertilizer and chemical products	-.049	.431
Production of building materials by NIC	-.089	.377
Production of hydrated lime building materials	.111	.335
Production of asbestos pipe and sheets	.109	.361
Production of concrete slabs, block	.155	.290
Production of kerbstone, concrete pipes and shafts	.135	.316
Sales of Kuwait Aviation Fueling Company	.519	.094[a]
Aircraft movement at Kuwait International Airport	-.031	.456
Gasoline sales in Kuwait	-.049	.428
Number of vehicles in use	-.052	.427
Area of paved road	-.064	.421
Production of refineries in Kuwait	.351	.094[a]
Amount of natural gas consumed in Kuwait	.057	.411
Amount of wasted and flared natural gas	.010	.486
Construction permits by area	.224	.211
Number of demolition permits	.238	.206
Area of agricultural holdings	-.434	.141
Total number of livestock (cattle, sheep, goats)	.573	.053[a]
Production of Kuwait Cement Company	.171	.261
Production of ready-mixed concrete	-.111	.343

[a]Significant at the < .10 level.

Table 9. Coefficient of Correlation between Monthly Measures of Human Activity and Poor Visibility Observations at 12:00 Noon.

Human activity variables	r	Probability
Production of refineries in Kuwait	-.056	.239
Aircraft movement at Kuwait International Airport	-.048	.261

Table 10. Coefficient of Correlation between Monthly Measures of Human Activity and High Visibility Observations at 12:00 Noon.

Human activity variables	r	Probability
Production of refineries in Kuwait	.089	.126
Aircraft movement at Kuwait International Airport	.037	.319

CHAPTER 7

CONCLUSIONS

Several conclusions may be drawn from this study. Most important, human activities are increasing in Kuwait along with rapid increases of population and capital investment. Despite this development, there is no corresponding deterioration in visibility as measured in this study. Instead, one finds great fluctuation over the past two decades. Although there is evidence to suggest that human activities do affect visibility (conditions on Fridays versus those on weekdays), no specific measure of human activity examined produces anticipated or statistically significant correlations with visibility variables. A number of reasons may be suggested for this failure to detect human effects on visibility, including an unexpected localization of effects, failure to identify the "right" human variables and possible lack of sensitivity in using annual production values. It is also conceivable that measures of visibility employed, especially long range visibility, are too restricted to detect a real deterioration. These points are addressed in the following paragraphs.

Generally speaking, human activity of every sort increased in Kuwait during the period in question, while visibility fluctuated downward and upward without showing a definite trend through time. It is possible that human activity in Kuwait has not yet reached a level at which it is a consistent determinant of visibility or, it is conceivable that the interaction of human sources of pollution and weather conditions regulating dispersal is exceedingly complex and undetected by this analysis.

It is also quite possible that visibility observations are very dependent on what is happening in the immediate vicinity of Kuwait International Airport. For example, burning natural gas from the oil wells scattered to the northwest of the airport may have had a great effect, yet this burning would constitute only a small fraction of the total natural gas burned in Kuwait. This localization of effects may also relate to rapid development very close to the airport, and to the dust which is raised by traffic moving around the airport. When development slowed and roads eventually were paved, dust would abate and visibility might improve to pre-development levels.

The measures of human activities used in this study were, in all but two cases, annual summaries. It may be that annual summaries are too insensitive to indicate short term effects on visibility. It may be necessary to use monthly, or perhaps even daily, data to detect significant associations. Yet the two sets of monthly data used also did not produce significant correlations, which leads to the question of whether the "right" variables were used.

Of course, not all human activities in Kuwait have been measured or are available in Kuwaiti government documents, and not all records available were used. My analysis is strongly biased towards production figures rather than figures for consumption. Consumption may have a greater effect on visibility. For example, production of gasoline by refineries may have less effect on visibility than the consumption of gasoline. Another class of variable may also be important, the effects of national and international pollution control policies. The implementation of pollution control programs and devices may have been highly effective, especially in the improvements shown by visibility in the late 1960s and early 1970s. However, the timing and nature of such innovation was not investigated in this study.

Perhaps the most obvious conclusion to be drawn from the study is that there is a great lack of direct information on pollution and pollution sources in Kuwait prior to 1976. Further investigation is required to clarify the relationship between weather factors, human factors and visibility situation in the country. From this study a number of recommendations can be made to help guide future investigations. The short term fluctuations of visibility should be looked at more closely, as well as the long term ones. Correlation should be attempted between visibility and human activities on a daily basis if possible. Also, local effects should be explored more closely, perhaps involving field observation and sampling of various activities in the vicinity of Kuwait International Airport.

The results of this study can also be used as a basis for recommending changes in collection of data. More precise monitoring of possible pollution sources should be made by government agencies and private business. The evidence presented in this paper indicates that pollution may have more important effects on long range visibility observations. Therefore, to obtain a more precise record of visibility changes it is important that visibility observations at Kuwait International Airport Weather Station return to the previous system of reporting on distances of long ranges of visibility (15, 20, 25, 30, 35 km).

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