THE SPATIAL RELATIONSHIP BETWEEN AMBIENT AIR QUALITY AND RESPIRATORY DISEASE IN TULSA COUNTY, OKLAHOMA 1984-1985

BY

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CHAPTER I

INTRODUCTION

Overview

Technology has advanced humanity's ability to cope with the demands of a dynamic world. Humans have increased the earth's carrying capacity through this technology in order to supply the basic components of life and also improve life's quality. The First Law of Thermodynamics states that energy can only be altered, not created or destroyed. In the creation of advanced technology for affluent societies, however, this alteration has had undesirable effects on the earth's biosphere. Consequently, the environment has become a waste dump for toxic byproducts of industrial societies.

Humans are intertwined with the elements of nature and occupy a dominating niche. They have created a "better life", but in so doing have altered the ecosystem by adding daily to the exponential growth of harmful air pollutants in the atmosphere.

Statement of Problem

A side effect of ambient air pollution is increased health problems. Modern medicine has begun to control and cure some of the leading causes of disease, but, according to Jackson (1986a), respiratory disease has experienced a great increase in the number of sufferers from 1930 to 1980. Jackson further states in a recent study that respiratory disease mortality has risen from the ninth to the fifth leading cause of death in the United States.

While many factors may contribute to this alarming report, however, the many gaseous and particulate materials added to the atmosphere daily are responsible in a large part for the increase in respiratory mortality. Lave and Seskin (1977) feel that the problem is of grave concern to scientists and policymakers alike.

Surveys show the typical person spends 90% of his or her time indoors, with much of that time being spent in the home (Mochandreas, 1979). The typical home has an infiltration rate (the rate of air exchange in a structure) of one to three times per hour; older homes, four to five times per hour (Williams, 1987). Therefore, persons with residences located close to major sources of air pollution might be expected to show higher incidences of respiratory disease.

Hypothesis

In an attempt to test the relationship between respiratory disease, pollution, and place of residence, the following hypothesis is presented:

> Spatial correspondence exists between places of residence of respiratory patients admitted to hospitals and the presence of poor ambient air quality.

As shown later in this thesis, ambiguity exists in the literature on methods of testing such a hypothesis. Either an analysis that is based on location of major sources of pollution or one that is based on interpolation of pollution data measured by pollution-monitoring stations might be used. The literature gives no guidance as to which method might be better for determining the spatial analysis of societal impacts. It might seem logical to apply two methods of measurement to test accuracy of the data and establish a precedent for future research. These methods will be operationalized in the following parallel sub-hypotheses:

H_a: The rate of patients with respiratory illness admitted to hospitals decreases with distance from major pollution sources.

H_b: The rate of patients with respiratory illness admitted to hospitals are relatively high when monitered air pollution levels are relatively high in their residential area.

Scope of the Study

Air pollution is a serious environmental problem in the United States, indeed on the earth, and in addition it has become costly and complex to control. It is the purpose of the present study to provide insight into the effect of high rates of pollution on people living close to major sources of pollution. It is known that there are high rates of respiratory distress in cities where industrial pollution is a problem. This thesis attempts to link major sources of a city's air pollution to the census tracts of patients who have been admitted to hospitals for respiratory distress.

Objectives and Procedures

The overall objective of this research is to relate the incidence of respiratory disease at place of a patient's residence to major sources of pollution. Specifically, the objectives are: (1) to establish confidence that respiraatory disease is greatly affected by air pollution; (2) to analyze the relationship between respiratory disease rates and pollution sources through statistical analysis; and (3) make conclusions based on the outcome of the analysis between the variables and decide the better method of measuring the pollution rate (H_a or H_b).

The above objectives will be achieved by the following: Chapter II will include a discussion on the increasing magnitude of the problem of air pollution and its consequences on the health of humans through a review of pertinate literature.

Chapter III will include a description of the characteristics of the study area. This includes the demographic, economic, topographic, and meteorologic facts that have been incorporated into the analysis.

An introduction of the methology for the study is included in Chapter IV. In addition, justification will be given as to the selection of different socioeconomic and patient variables. A description of the analysis and its conclusions will be given in Chapters V and VI respectively.

CHAPTER II

LITERATURE REVIEW

Individuals at Risk

The task of proving cause and effect between respiratory disease and air pollution is difficult. Intervening variables tend to complicate the outcome of most research. For example, a sixty-year-old man suffering from bronchial distress is treated in a neighborhood hospital. For the past twenty years he was employed as a yard worker at a local rock crusher plant. He has smoked for the past thirty years and has had poor nutrition. In addition, he lives in an industrial section of the city. In this example, it is impossible to establish a cause of the disease. Regardless of these complicating interventions, students of research must attempt to determine if there are overriding conditions in the environment that bring about deleterious health conditions. The relationship of respiratory disease to air pollution can be examined epidemiologically when certain factors become clear.

It is important to state here that inferences involving causal relationships are to be addressed carefully. Often, analyses are drawn from the micro level and imputed as factual at the macro level. This is often referred to as the individualistic fallacy. More often, however, the reverse situation occurs. The ecological fallacy describes a circumstance in which inferences are drawn from a totality and imputed to individuals. These are common errors in studies involving causal inference. The present study will seek to avoid such inferences by reporting and addressing only the findings of the analysis.

Jackson (1986a) states that deaths due to malignant neoplasms, or cancerous tissues, have increased slightly among Americans in general; some of the increase in cancer mortality is due to a sharp rise in malignant neoplasms of the respiratory system. Ayres (1969) investigated vital statistics and hospital admission records to find that temporal connections exist between episodic concentrations of pollutants in the atmosphere and human health. Some evidence suggests that air pollution emitted by the burning of fossil fuels in the United States contributes to the premature death of at least 53,000 people each year (Wilson, 1981). This number only represents diagnosed respiratory illness deaths. Many other deaths are suspected to be caused by pollution but are attributed to other causes. Lee (1972) urges agencies and researchers to present reliable estimates of the role of environmental factors in respiratory disease cases and further adds that these factors be used as a basis for rational control action.

Researchers have attempted to associate respiratory disease and poor air quality. They have drawn from a number of data sources and several of these studies are reviewed here to support the hypotheses of this thesis.

Commoner (1971) suggests that environmentally harmful technology, since World War II, has been the major source of pollution in industrialized affluent nations. He further states that technology has shifted much of their production and consumption from natural products that can be broken down, diluted, or absorbed by natural processes to synthetic products that often cannot be degraded by natural processes.

Urbanization of society brings humans into close proximity with many sources of atmospheric pollution. This spatial agglomeration appears to increase respiratory problems. An example of the increasing health problem to humans today is the introduction into the environment of hazardous chemical pollutants believed to be carcinogenic or mutagenic (Lakshmanan, et al, 1977).

Disease patterns have been altered and humans are living longer. In the early 1900s, life expectancy was sixty years, and today that expectancy is seventy-two years (Brown, 1985). In 1930, before antibiotics, the annual death rate from lobar pneumonia was 45.3 per 100,000, by 1960 it had dropped to 5.6 per 100,000. Similarly, tuberculosis was responsible for 194 deaths per 100,000 in 1900, and by 1950 the rate had declined to 22.5, and in 1967 to 3.5 per 100,000 (U.S. Bureau of Statistics, 1969). On the other hand, in New York City chronic bronchitis and emphysema were held responsible for a combined death rate of ten per million in 1950; by 1965 the rate had risen to seventy per million--a seven-fold increase in only fifteen years

(Denson, 1967). Whereas the top five leading causes of death have declined, chronic obstructive pulmonary diseases and cancer have increased significantly. If modern medicine has begun to control the major causes of death in this country, why are the numbers for chronic obstructive pulmonary diseases increasing? It is possible that ambient air pollution is a cause for this increase.

For the past few decades, personal pollution, i.e. smoking, has been suspected as the main culprit for increased incidents of lung cancer. The number of people who smoke has, however, declined in the past two decades (National Center for Disease Control, Atlanta. 1987). Mason (1975) states that those who smoke increase the likelihood for the greater risk of lung cancer due to the destruction of delicate cilia filters and mucus producing membranes. These filters and membranes are protection devices used to guard against foreign particles and harmful toxins in the atmosphere. It would seem, therefore, that those who smoke would be more affected by air pollution than those who do not smoke.

Mortality versus Morbidity

A review of the literature indicates that most research is conducted with mortality figures from city-county health departments. The reasoning for this is quite simple. Mortality data are readily available, supplied by the local city-county health departments. The numbers supplied by these records for a given area are small and are therefore difficult to test statistically and spatially. In addition, mortality studies only supply the researcher with facts after death has already occurred. Preventative medicine is the thrust for the present-day medical profession.

With the foregoing reasons in mind, there are two reasons to research the occurrence of disease before death: (1) There are larger populations being treated for disease, thus a larger number of observations to study. A larger sample size should also address the problem of migration to a certain extent, and (2) knowledge of where respiratory disease is occurring, provides facts which might provide health/environmental specialists with data to improve a community's health.

Seemingly little morbidity research has been conducted using actual patient records. An apparent reason for the lack of research in the area of morbidity, is the unavailability of patients' records. Data available from epidemiological studies are often held in confidential files and their use is prohibited by law. On the other hand, county health departments are required to record mortality data for public use, thus the data are readily available. Individual morbidity studies must, therefore, rely on the sympathetic resources of doctors, health department personnel, and hospital administrators. Consequently, the spatially-oriented morbidity research literature is limited. A lack of standardized records, the time-consuming task of acquiring authority to collect the data, and the data collection itself, usually inhibit such studies.

The present study utilizes actual patient records that have been provided by hospitals within the study area. Because hospital patient records are seldom made available to research, much research is conducted through laboratory-controlled studies.

Laboratory Controlled Studies

Laboratory controlled tests can be utilized to determine the ill effects of certain pollutants on body functions. Laboratory studies have been relatively recent. Before 1970, most of the results of air pollution effects came from laboratory animals or epidemiologic observations of people exposed to pollutants in the course of their normal activities. However, Lave (1977) concludes many factors such as physiology, life span, and exposure that make it seemingly impossible to extrapolate from the results of animal studies to the effects of human beings. Lave has determined that

> ... our most useful information on the underlying physiological mechanism comes from the highly controlled laboratory animal experiments and short-term fumiation experiments on humans.

Researchers indicate that such experiments, however, may still provide the public with very little direct information regarding the factors affecting disease in man. Lee and Mudd (1970) make the following statement:

> Controlled human studies may be defined, for all purposes, as laboratory experiments in which volunteer subjects breathe atmospheres

> containing a single pollutant substance or relatively simple combinations of substances under well-documented and well-controlled environmental conditions, realistically simulating real-world polluted environments of health interest.

They further expand their definition by adding that animal-controlled studies usually precede the human studies to determine the most toxic pollutants. Some tests use breathing masks but this is not desirable. Controlled environmental chambers allowing for activity of subjects is another method of controlled testing. The problem, again, with these studies is that only relatively mild health responses may be studied ethically.

An example of such a study was conducted by Bates and coworkers (1976). These researchers used ozone (O_3) at 0.37 and 0.50 parts per million (ppm) in a laboratory study to obtain results that showed those subjects who were predisposed to adverse reactions were people with a preexisting respiratory disease, i.e., asthmatic victims.

It would seem that controlled human studies can provide a major part of the scientific guidance for pollution control planning and air quality standard setting. There has been recent progress in this field, but there are still some problems in experimentation and interpretation of results. It is suggested by Lave (1977) that

> ...animal biology should concentrate on long-term effects of repeated exposures and on the relationships between short- and long-term effects. Human studies are ethically limited to short-term reversible toxic effects; thus, the judgement whether short-term effects are linked to long-term irreversible damage must be

based on observations in animals.

In order to identify and understand health problems affected by air pollution and in order to avoid ethical problems, there should be greater emphasis in natural experiments involving humans. Thus, the epidemiological approach to investigating the effects of air pollution must look beyond the controlled studies to actual morbidity research. Suess, Grefen, and Reinisch (1985) make the following statement "...experiments on humans are usually limited to healthy persons of a certain age group." Lave (1977) adds "...the basic task becomes one of making inferences from observational (nonexperimental) data."

Observational (Uncontrolled) Studies

The present concern over the quality of the atmosphere arose largely from epidemiological studies, which suggested that human populations exposed to certain substances present in the air suffered deleterious effects, which could be ascribed to these substances. Unfortunately, such studies detect only the more advanced stages of the environmentally induced disease and do not provide sensitive procedures for detecting early events.

The first documented victim of air pollution by sulfur oxides was Plinius the Elder. He died as Admiral of the Roman Fleet in 79 A.D., during a rescue operation when Mt. Vesuvius erupted in Italy. Tacitus reports that Plinius collapsed on the beach after inhalation of the volcanic fumes. He added that Plinius already suffered from airway obstruction before he took part in the rescue operation (Weinstein, 1980).

Mills (1943) studied cancers of the upper air passages in Cincinnati. He found that there was a 56 percent higher rate in the more polluted parts of the city than in the cleaner parts of the city.

In the United States, Mills (1943) also studied wards in Pittsburgh and Cincinnati, during 1929-30. He reported significant correlations between pneumonia death rates and pollution as measured by sootfall. The actual variation in the corresponding death rates was 0 to 7,852 per 100,000 population for Pittsburgh and 41 to 165 per 100,000 for Cincinnati. Mills also found that death rates fell significantly as the altitude of an individual's residence increased.

In an additional study Mills (1952) examined age-sex-race-specific, respiratory-tract cancer mortality in Chicago and observed that high rates for elderly males occurred a decade earlier in the most polluted (sootfall and sulfur dioxide) sections of the city than in the cleaner sections.

In 1952, there was a dense fog over London that lasted several days, and the mortality numbers showed the effect of air pollution very clearly. There were 4000 extra deaths in the wake of this serious air pollution episode. Air sampling at that time was still in its infancy, but the air pollution levels of sulphur dioxide (SO_2) and smoke were around 5 milligrams per cubic meter in Central London. "The bulk of epidemiological studies have been compiled in London, most of which have been convincing" (Cohen, 1969).

Zeidberg (1967) studied mortality in Nashville and found that total respiratory disease mortality (age-sex-race-adjusted) was directly related to the degree of sulfa-ion (sulfur trioxide) and soiling (concentration of haze and smoke), although death rates for some specific diseases followed no definite pattern.

A study by Shy and coauthors (1973) indicated relationships between acute respiratory illness and nitrogen dioxide exposure across areas of Chattanooga, Tennessee. Using a biweekly survey in 1969 for a 5 month period, 871 families (4,043 individuals) were analyzed. These subjects lived in five different neighborhoods: three in high exposure areas and two in areas that experienced low exposure to nitrogen dioxide. It was found that those individuals living in a proximity to the high nitrogen dioxide exposure had a higher incidence of respiratory disease. The excess was not explained by differences in family composition, economic levels (market value of home), education of family head, or prevalence of chronic conditions. No meteorological factors entered the analysis.

In Great Britain, Rosenbaum (1961) studied the rates of respiratory disease in British servicemen and their place of home residence. Rosenbaum discovered that if the servicemen's home was near an industrial region, he was more susceptible to respiratory diseases.

Several studies of cancer mortality within major U.S.

cities have been analyzed and mapped. The results indicate a definite relationship between high death rates and major industrial areas with high indices of poor quality ambient air (Greenburg, 1977). Because places of residence can be polluted by major industrial areas and their emissions, Greenburg suggested that respiratory disease rates may be related to places of residence.

Heimann (1970) found that patients in Boston suffering from chronic nonspecific respiratory disease, such as bronchitis, made more visits to chest clinics. The pollutants analyzed were suspended particulates, sulfur dioxide, and a soiling index, referred to as particulate matter.

Controlling for weather conditions, Holland, Spicer, and Wilson (1961) successfully correlated hospital admissions in London for treatment of respiratory diseases and air pollution. Heart disease admissions were not found to correlate with the meteorologic variables.

In Los Angeles, Sterling and coauthors (1966) statistically correlated hospital admissions with several different pollutants (oxidants, carbon monoxide, sulfur dioxide, nitrogen dioxide, nitric oxide, total oxides of nitrogen, ozone, and suspended particulates), humidity, and temperature. Significant associations were found for acute upper-respiratory-tract infections, as well as bronchitis.

Silverman (1973) examined emergency hospital admissions at 22 Pittsburgh, Pennsylvania, hospitals. He controlled for temperature, precipitation, and day of the week. He discovered that respiratory diseases, and in particular bronchitis and pneumonia, were significantly associated with suspended particulates.

In Japan, Hitosugi (1968) surveyed the families (259) of victims of lung cancer. In addition, he took a random sample of 4,500 adults (age 35 through 74 years of age). Variables included age, sex, smoking habits, occupation, residence, and previous medical history. Different types of air pollution were related to the areas of residence. Results indicated increases in lung cancer mortality among smokers and ex-smokers where pollution levels were higher.

Many studies concerning health and air pollution have been conducted in England. Unique environmental conditions, including climatology, urban crowding and industrial-residential burning of fuel for heat and power, are the impetus for the bulk of these studies. According to the Registrar-General (1968), chronic bronchitis is one of the major causes of disablement and death, particularly among middle-aged and elderly men.

Bronchitis appears to be an indicator of the presence of air pollution in a number of previous studies. Reid, et. al., (1964) found through the Planned U.S. British Comparison that the British exceeded Americans very little in prevalence of simple chronic bronchitis. Because bronchitis produces large numbers of hospital patients and because it has been successfully tested in previous studies, the present study will use acute and chronic bronchitis hospital admission numbers to acertain the presence of air pollution in a given area.

Age

Age appears to be a factor in contributing to correlations between morbidity and air pollution. Studies commonly have controlled for age and it appears that above the age of forty-five their is a greater incidence of respiratory problems. Examples of this type of research includes such studies as Holland and Stone (1965). These researchers found groups of males who were similar in age and smoking habits and who worked in London, had worse bronchitis and poorer function of the lung than those in the cities of the eastern seaboard of the United States, or in the smaller towns of England. The difference was most marked in Londoners over the age of 45.

In addition, Greenburg and coauthors (1967) researched high levels of sulfur dioxide and smokeshade in New York City in 1963. Many excess deaths, 200-400, were attributed to air pollution. The victims were people over the age of 45.

Zeidberg, Prindle, and Landau (1964) discovered that strong relationships exist between residential areas with high rates of air pollution and total morbidity. The correlations were greater among those who were 55 years of age and older.

Carnow and coauthors (1969) researched 561 sufferers of chronic bronchopulmonary disease in Chicago. They analyzed the daily pollution index of sulfur dioxide levels in a square mile around place of employment and residence. Patients, age 55 and older with "advanced bronchitis", experienced exacerbated symptoms on the day when sulfur dioxide levels were high, as well as the following day.

Winkelstein and Kantor (1969) used questionnaires to analyze the relationship between cough and air pollution among 842 white females in the Buffalo, New York area. A positive association was found between suspended particulates and cough (with phlegm) in nonsmokers (aged forty-five and older) and among smokers who had not moved within the previous five years; among smokers who had moved, the association was inverse. No associations were found between cough and sulfur oxides. In addition to age, sex, race, smoking, and residential mobility, years of schooling and history of bronchitis were considered.

Sauer and coauthors (1966) analyzed Georgia and North Carolina to find higher death rates in metropolitan areas (white males aged forty-five to sixty-four and thirty-five to seventy-four, age-adjusted) than nonmetropolitan areas. They did not account for any other factors.

In Great Britain, Gardner, Crawford, and Morris (1969) determined a positive and significant association between respiratory disease rates and air pollution. Their study was limited to males aged forty-five to sixty-four.

Berry (1976) concludes, "Since 1970 there is a greater uniformity of groupings of people in communities according to class, race, age, and language." He gives the example of the central city as now having become the home of the nonwhite, poor, and the aged. Timms (1971) suggests that the younger and middle-age families tend to inhabit the zones further away from the CBD.

The research of this thesis will address only those individuals over the age of 45. In so doing, the age hierarchy which exists outward from the central city in most communities can be ignored.

The Spatial View of Disease

A review of the literature gives evidence that few studies have been conducted in small geographic areas on the problem of air pollution and respiratory disease. Stadler (1979) addresses the fact that there has been a lack of sophisticated spatial approaches to looking at health effects of pollution. According to the bulk of the literature, large observation units such as whole countries, states, counties, and/or cities are normally utilized. In light of the need to conduct research with small areal units, Meade (1986) suggests that "...random variation can be better avoided and data stabilized by use of large scale observation units. Friedman (1974) concurs with Meade by adding,

> When studying disease occurrence within a city, it is often desirable to plot the occurrence of disease in each census tract, since information about other characteristics in each tract is available.

The present study will therefore utilize census tracts as the spatial observation unit by which the data will be tested and mapped.

Early Studies in Medical Geography

Medical geography is not a new concept in the research of disease and other health-related problems. Mapping of disease-related phenomena was becoming common in the nineteenth century. Heinrick Berghaus' Physical Atlas (1848) included a world map titled, "A Global Overview of the Geographical Spread of the Most Important Diseases to which Mankind is Exposed Throughout the World." This first known map of diseases attempts to show a world distribution of diseases such as cholera, elephantiasis, goiter, and smallpox (Meade, 1980). Fuchs (1853) defined medical geography as the knowledge of the laws according to which diseases are distributed and spread throughout the world. Muhry (1856) used isotherm maps to establish spatial limits of malaria, typhoid, the plague, cholera, and yellow fever.

Cartography has often been used to study the spatial distribution of diseases. Since the early part of the twentieth century, medical geographers used mapping techniques to display the diffusion process of diseases. Federal agencies began mapping diseases in the 1970s to help explain trends in health-related phenomena (Pyle, 1979). The proposed research will utilize mapping techniques to help discern possible relationships between respiratory illness and polluted air.

Perhaps one of the best known studies in medical geography was accomplished by G. F. Pyle (1969) on the diffusion of cholera. His maps indicated that cities were the transmitting nodes for this dreaded disease of the 1800s.

Early studies in the field of medical geography were not always conducted by geographers. Meade (1980) explains that

> The early pioneers to the field of medical geography were mainly physicians and used the empirical rather than the theoretical or hypothetical approach. In addition, they viewed the earth from a holistic position and therefore sought to comprehend individual medical cases by synthesizing them into a whole. By using the scientific-approach they attempted to address the laws of disease distribution.

Geographers have long been interested in spatial differences in disease and human well-being, but of course have only recently gained the data of sufficient precision and in sufficient amounts to make meaningful analyses.

Recent Studies in Medical Geography

Cartographic, ecologic, and other approaches to the study of disease, environmental conditions, and provision of health care are being taught in many university geography departments throughout the world (Picheral, 1984). In Canada much attention is centered on the study of the relationships between pollution and disease and is seen as a promising research area for the future (Thorrez, 1983).

The application, technique, and understanding of geomedicine is rapidly undergoing change on an international scale and is, therefore, not unique to North America. Progress is being made in understanding the spatial distribution of health problems in Europe, Asia, and tropical Africa (McGlashan, 1983).

The Center for Disease Control in Atlanta, Georgia. with its computer mapping section, now provides many spatial distributions of selected diseases at the national level (Center for Disease Control, 1976). The recently published National Atlas of Cancer was, for example, developed largely with computer-drawn maps (Mason, et al., 1975). Integrated health information systems are now being implemented to accomplish necessary data handling in geographic base files developed in conjunction with the United States Bureau of the Census. Models are used that incorporate socioeconomic resources, hospital inpatient and outpatient care, ambulatory care, assessment of quality care, and a variety of other layers of information.

The interdisciplinary approach to research with cognate fields such as medicine has long been a goal of the field of geography. The use of data such as patient's records gives validity to spatial studies. Prothero (1983), in relating his studies in tropical Africa, states,

> A balance has been struck in disease study schemes where geographers have acted as consultants...the most fruitful research is achieved when geographers and medical researchers work together.

The present study will use hospital records of medially-diagnosed patients who have been admitted to hospitals for the treatment of respiratory disease. The patient data will be mapped and statistically tested along with certain socioeconomic data and pollution rates aggregated by census tract.

Effects of Certain Pollutants on the Respiratory Tract

<u>Bronchitis as an Indicator</u>. This study will utilize the incidence of acute and chronic bronchitis cases admitted to hospitals within the study area. The literature gives evidence that bronchitis can be used as an indicator of the presence of poor air quality (The Ministry of Pensions and National Insurance, 1965). In Great Britain there is much support that chronic bronchitis is one of the major causes of disablement and death among middle-aged and elderly men (Registrar-General, 1968). Whereas lung cancer develops over a period of many years, bronchitis sufferers respond to the day to day high and low levels of deleterious substances in the atmosphere. It is, therefore, a better day-to-day indicator of the presence of air pollution.

There is, also, the matter of acquiring patient data for sufferers of acute and chronic bronchitis. Lung cancer is generally studied after the patient dies and these mortality figures are readily available. Death can occur from bronchitis after years of suffering from the day-to-day stress of air-borne materials, but those patient data are not a matter of public record. Therefore, fewer studies are conducted because of the lack of pertinent data and the larger numbers supplied by illnesses. The present study uses data acquired from major hospitals within the study area. The study therefore has the potential to alert those concerned with air quality research about the immediate effect of air pollution on people living close to major sources of pollution.

Air Passage through the Respiratory Tract

Air enters the body through the nose which filters particulate matter larger than 10 micrometers in diameter (Figure 1). It then passes into the pharynx, esophagus, larynx, and finally to the top of the trachea. The trachea branches into the right and left bronchi. Each bronchi divides and subdivides at least twenty times and the smallest units, bronchioles are deep into the lungs. The bronchioles end in some three million air sacs, the alveoli.

During passage through the respiratory system, soluble gaseous pollutants are almost completely removed by the moist mucous membrane lining. Particulate matter 0.1 - 2.0 micrometers may reach the alveoli; once a solid particle reaches the small airways and alveoli, its residence time is measured in weeks, months, or years. Sulfur dioxide may reach the alveoli when the gas is either sorbed on small particulate matter or oxidized to a sulfuric acid aerosol of proper size. Inert particulate matter, sorbed gases on particulates or corrosive liquid aerosols may irritate the bronchi and breathing sacs. This causes damage which diminishes the ability of the bronchopulmonary structures to function properly. It may also predispose them to chronic bronchitis, emphysema, and other respiratory diseases (Stern, 1977).

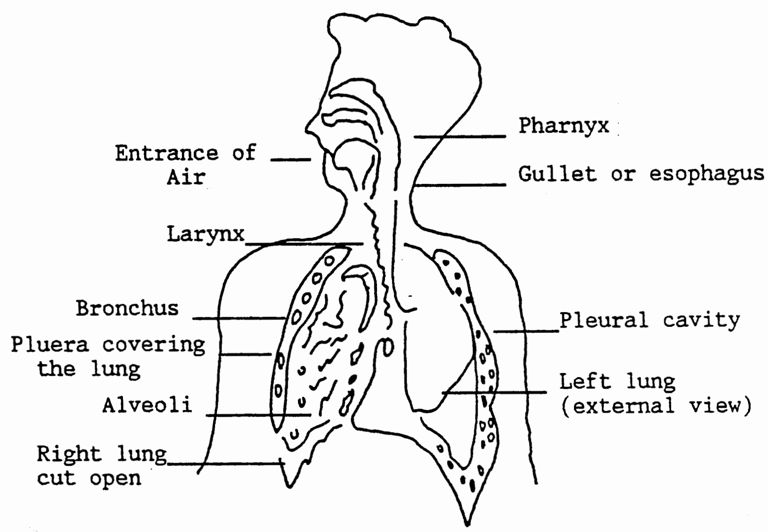


Figure 1. Human Respiratory System

Silverman (1973) addressed the problem of daily emergency hospital admissions in Pittsburgh, Pennsylvania. Twenty-two hospitals were studied for emergency admissions. Temperature, precipitation, and day of the week were examined. Silverman found that those patients treated for respiratory diseases (bronchitis and pneumonia) were significantly and positively associated with measures of suspended particulates. It is therefore conceiveable that the patient and pollution data of the present study might be successfully correlated. Hospital admission records from local hospitals within the study area can supply patient data to study the effects on humans from known measures of air pollution. The literature clearly reveals that a study conducted on a fine scale such as census tract levels can produce significant levels of relationships between the variables.

CHAPTER III

CHARACTERISTICS OF THE STUDY AREA

General

The study area for this resesarch is Tulsa County Oklahoma. Tulsa is one of 77 counties in the state of Oklahoma (Figure 2), and has a total area of 376,320 acres (929,886 hectares) or 588 square miles (226 square kilometers). The city of Tulsa acts as a hub to twelve smaller cities/towns located within the county and is the most industrialized city in the state. It is, therefore, likely to have problems with large amounts of polluted air. Even with the closing of many of the oil refineries within the county, the air quality does not meet the Environmental Protection Agency's standards of compliance.

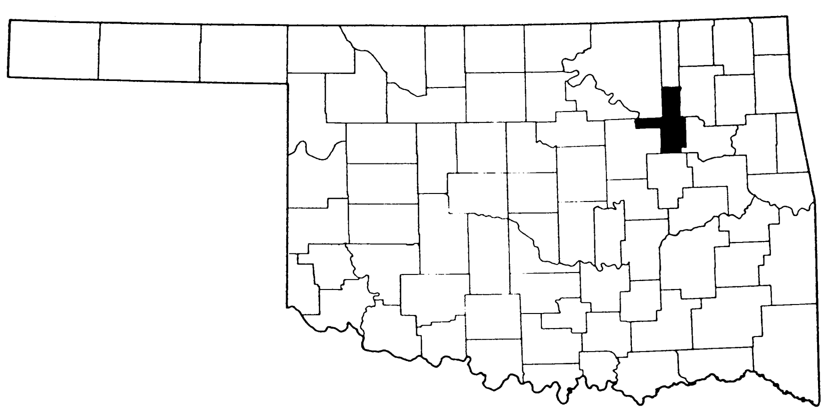


Figure 2. Tulsa County's location within Oklahoma

Topography and Natural Features of the County

The topography of Tulsa County includes some lakes and a major river, the Arkansas, which serves as a base for several industries. Rolling hills dominate the western portion of the study area along the river basin where relief is greatest. The remainder of the county is relatively flat with some small differences in elevation, ranging from 700 to 1000 feet. The higher elevations follow the river channel, forming valley walls (Figure 2).

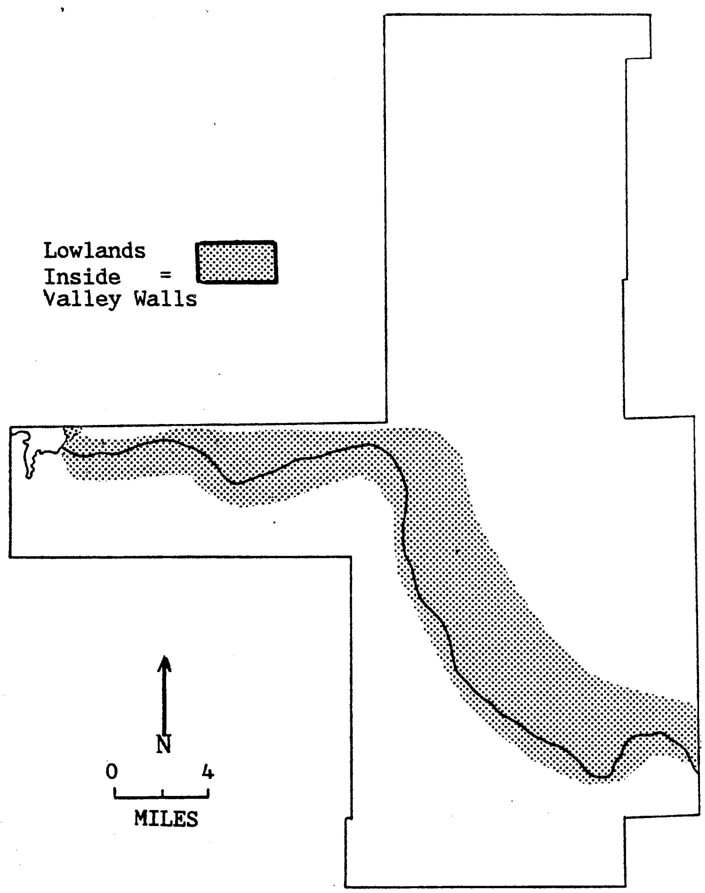


Figure 2. Valley walls formed by the Arkansas River in Tulsa County, Oklahoma

Topography generally influences temperature and wind patterns in an area, and may be a consideration in pollution patterns and the incidence of respiratory disease within the county. This seems reasonable for Tulsa County as most of the heavy industry is located along the river channel in the lower elevations (See Climatology).

Climatology

The climate in the county is considered Cfa (McKnight, 1986) because of the hot and humid summer and cool and humid winter seasons. The meteorological data includes average annual winds from the southeast at 10.7 miles per hour (Tulsa City-County Health Department, 1985). These wind speeds could be responsible for slow removal of pollution plumes within the county. Winds fluctuate greatly and are affected by the local topography. Valleys are protected by the valley walls from high wind speeds. Pollution clouds can therefore be greatly affected by wind and the presence of hills and valleys in a given area (See Topography). The winds can be directed through river channnels where the ridge elevations are high and/or pollution can be trapped there through the phenomena know as temperature inversion. The mixing of the air, or the lack thereof, and its effect on pollution, will be addressed in chapter 5.

Population

The 1980 census reported a total population of 470,593 for the county (Census, 1980). It is expected that a population of this size should produce adequate numbers of respiratory patients admitted to hospitals to make the present research viable. Clark and Hosking (1986) conclude that conducting a pilot study to determine if certain parameters are present is a satisfactory method of determing whether the sample size is adequate. A pilot study was conducted using numbers of patients per zip code to determine if patterns were present within the county (Allen, 1986). The results of the study were mapped and indicated that definite patterns were present. There were varying degrees of the incidence of respiratory disease throughout the county with concentrations heavy in the downwind direction of prominent sources of pollution.

The median age for Tulsa County is 29. The present study will address only those people who are 45 years of age and older because of their greater likelihood to contract respiratory disease. The literature review revealed that the number of people who suffer from respiratory disease begins to increase around the age of 45. The total population in Tulsa County for this age (45 and up) is 137,107, comprising 27% of Tulsa County's population.

Race

Statistics from the 1980 Census indicate that 15% of Tulsa's population is non-white. The non-whites tend to have higher fertility and mortality rates, therefore there are more youth and less elderly in this group. Jackson (1986a) states,

> Mortality rates for non-whites in the U.S. tend to exceed those for whites. Much of this difference has been linked to socioeconomic factors which influence access to health care, awareness of disease risk factors, and early diagnosis and detection.

Jackson further indicated that black mortality rates for most leading causes of death exceeded those for whites by 47.6%. She attributed, among other causes, environmental and occupational exposures to this high percentage rate, adding that a large number of minority groups live in the cities where they are constantly exposed to environmental hazards such as pollution and substandard and overcrowded housing.

The race breakdown of Tulsa County is similar to that of the United States. Table I gives a breakdown of the race of Tulsa County and the United States.

TABLE I

TULSA COUNTY AND UNITED STATES PERCENT POPULATION BY RACE

Place	% White	% Black	% Native American	% Spanish	% Asian	% Other
Tulsa	85	9.28	4.05	1.62	.65	.91
U.S.	83	11.70	.6	1.50	6.40	.50

Source: M. Brown, "Demographic Characteristics of the Population," Tulsa: Today and Tomorrow (1986).

Because a high percentage of minorities within an area is usually indicative of low status neighborhoods, researchers often utilize race as an indicator for the pathology of an urban society (Harries and Stadler, Zdorkowski, 1980). This study will consider race by using percent Black population by census tract as a portion of an Urban Pathology Index (UPI). The UPI is explained in Chapter IV.

Economy

The economy of the county is dynamic because of recent changes in the gas and oil market. The oil economy suffered in the early part of the 80s and as a result, many of the refineries in the county were closed. Air pollution problems have been lessened as a result of these closings, however some industries in the county are still out of compliance with the Environmental Protection Agency's standards.

Tulsa's housing costs are above the Nation's average by 13% (Jackson, 1986b). Median family income in Tulsa for the 1980 Census was reported at $21,125. Income is an excellent measure of a society's pathology. Median family income will be included in the urban pathology index of the present study. Housing information is a valuable measure to assess a given area. Substandard housing is normally added as a housing dimension in an urban pathology indices. and will be employed as a third variable in the urban pathology index utilized in this thesis.

Time Period for Study

January 1, 1984 through December 31, 1985 is the period of time for the study. Acquiring necessary patient data from hospital records on a select basis would have been an impossible task without the facility of magnetic tape. There was no documentation of hospital admission records by computer entry before 1984 in Tulsa County hospitals. This is not a major problem, however, as the industrial pollution patterns before this date would have appeared dissimilar to the 1984/1985 data because of the shutdown of many of the oil refineries in the County.

Monitored Air Pollution

The Environmental Protection Agency (EPA), has become responsible for the cleaning of the air. The Clean Air Act of 1970 (Vig, 1985) is the mechanism through which the agency performs. In April of 1971, the EPA issued the first air quality standards for the nation. In conjunction with the setting of these standards, air pollution control stations have been situated throughout the county to monitor the air quality. The placement of these stations is in conjunction with where major sources of air pollution exist, where transported materials may enter the county from the upwind (southerly) direction, and where polluted air within the county may be transported downwind. The types and number of pollution monitoring control stations in the county are listed in Table II, and the site locations are displayed in Figure 4 in Chapter IV.

TABLE II

NUMBER AND TYPES OF POLLUTION MONITORING STATIONS

Carbon Monoxide	Ozone	Nitrogen Oxide	Sulfur Dioxide	Suspended Particulates	Lead
2	3	3	2	13	2

Source: Tulsa City County Health Department's Annual Report (1984/85).

The following is an accounting of the different pollutants that the EPA requires cities to monitor. Characteristics of each pollutant and its effect on the human body, namely the respiratory tract, is also addressed.

Carbon Monoxide

Carbon Monoxide (CO) is a highly poisonous gas responsible for half of all fatal poisonings in the United States each year (TCCHD, 1985). Such poisonings are routinely reported to the health department in Tulsa each winter because of heating units which malfunction and suicide deaths. CO is emitted by heating gas, coal, or wood. In addition, CO is produced by the distilling of coal or wood to obtain other products by the use of kilns, forges, or other burning processes where incomplete combustion occurs. The major environmental source of CO is the automobile (TCCHD, 1985).

Ozone

Ozone (O_3) in Tulsa was a severe pollution problem in 1985 (TCCHD, 1985). Its formation begins when hydrocarbons and nitrogen oxides emitted before sunrise accumulate in the atmosphere. When solar radiation is available, a complex chemical reaction occurs with ozone being the major product. Peak levels are closely associated with wind speed and direction. Temperature inversions and other meteorological and topographic factors add to the severity of the problem of ozone (Suess, Grefen, and Reinisch, 1981).

Sufferers of chronic respiratory disease are greatly affected from exposure to oxidants such as ozone. It irritates the eyes, throat, and lungs. It is believed to impair the function of pulmonary macrophages and induces thickening of the walls of small pulmonary arteries, thus leading to chronic pulmonary disease and emphysema (Suess, Grefen, and Reinisch, 1981). Because of the large number of sunny days in the Tulsa and the persistant use of the automobile, ozone will continue to be a problem. (TCCHD, 1985).

Oxides of Nitrogen

Oxides of Nitrogen (NO_x) are the toxic components of automobile exhaust, discharges from refuse incinerators and power plants, products of combustion of coal, oil and natural gas and are the precursors of ozone (O_3). Nitrogen dioxide (NO_2) persists in the atmosphere. It is the oxidation product of Nitric Oxide (NO) which is produced by fixation of atmospheric nitrogen with Oxygen during high temperature combustion. NO is relatively non-toxic at ambient concentrations whereas NO_2 has been shown to produce serious health effects. NO_2 produces effects at the histological, hematological and behavior levels and appears to increase susceptibility to respiratory illness. NO_2 is almost insoluable in water and therefore passes through relatiively dry upper respiratory areas into the moist alveolar area of the lung (Figure 1) where it forms Nitrous Acid (HNO_2) and Nitric Acid (HNO_3), both of which are very corrosive to the tissues. Studies have shown an association between increased incidence of acute respiratory disease and exposure to NO_2 in the range of 150 to 280 micrograms per cubic meter (Suess, Grefen, and Reinisch, 1981). These levels are often reached and surpassed in Tulsa during a typical summer day, however, exposure length is very short as these high levels quickly dissipate (TCCHD, 1985).

Sulfur Dioxide

Sulfur Dioxide (SO_2) is a toxic gas produced by the burning of coal, oil, refuse, wood, and other sulfur containing products. It is also a by-product of ore processing and the making of paper or sulfuric acid. When it becomes oxidized and dissolved in water, it produces acid rain and mist. SO_2 alone is probably not responsible for the many adverse health effects associated with it. Sulfate particles, products of aerochemical conversions of SO_2, are more likely to be the offenders. However, epidemiological studies have revealed a significant increase in morbidity in older people who already had severe bronchitis after exposure to increased levels of SO_2. Throat irritation, cough, eye irritation and bronchial constriction are all related to exposure to SO_2 (Suess, Grefen, and Reinisch, 1981)

SO_2 levels in Tulsa County have never been a problem. The highest Annual Arithmetic Mean for 1985 was 62.9 micrograms per cubic meter. The national maximum allowable is 80 micrometers per cubic meter (TCCHD, 1985).

<u>Total Suspended Particulates</u>

Total Suspended Particulates (TSP) is a criteria pollutant consisting of any matter, solid, or liquid (other than uncombined water vapor), which is suspended in the ambient air. The duration of suspension is directly related to the size of the particle. Small particles (0.3 to 10.0 micrometers) are inhalable particulates; these may remain suspended for weeks, whereas larger particles (50.0 to 500.0 micrometers) may be suspended from only a few hours to a few seconds. When an individual breathes particles smaller than 10 micrometers, they are inhaled deep into the lungs where they will remain. Particles larger than 10 micrometers are filtered or trapped by the nasal hairs and cilia of the upper respiratory system where they are expelled from the body by natural cleansing processes (Suess, Grefen, and Reinisch, 1981).

The major sources of TSP in Tulsa County are fugitive dust, (blown from bare soil), industrial sources, and diesel exhausts. TSP is measured by thirteen of fifteen air pollution monitoring control stations situated throughout the county and is measured at 98% efficiency (TCCHD, 1985).

Summary of Pollution Types

All of the foregoing pollution types are hazardous to the health of humans and all are contributors of the air quality in Tulsa County. TSP is the only pollutant that has several monitoring stations. Because the literature revealed that most studies found a higher correlation between respiratory disease and a soiling index (TSP), TSP will be employed in this study to support subhypothesis H_b. The other pollutant types that are mentioned here, as well as TSP, would be utilized in analyzing H_a, a distance measure to sources of pollution from the centers of census tracts. These pollution types will not be analyzed by kind, but the industries producing the emissions will be utilized to measure the distances from their plants to the centers of each census tract.

Conclusion

Tulsa County is the most industrialized county in the state of Oklahoma and supplies the present study with a diverse amount of industry, including oil and gas, steel, chemical, electrical power, glass fabrication, and many more. The air quality is closely monitored by professionals who encourage industries to comply with the Environmental Protection Agency's standards.

The population size provides numbers where one might expect a large and diverse sample of people suffering from respiratory distress. The present study utilizes admission records of the three largest hospitals as data base for several patient variables. It is expected that the resulting analysis should indicate that there is a spatial relationship between the hospital patient data, the socioeconomic data, and the pollution data.

CHAPTER IV

METHODOLOGY

Overview

> The field of medical geography is increasingly quantitative and with the implementation of statistics, computers, and accepted methodologies, the field can only continue to grow (Pyle, 1983).

The research to examine the relationship between place of residence of respiratory disease patients and air pollution in Tulsa County, Oklahoma, was conducted using hospital admission data for a two year period, 1984 and 1985. In addition to the hospital data, air quality records were obtained for the same time period. Census data were extracted from the 1980 Census of Housing and Population to produce an Urban Pathology Index. The index was employed to assess the socioeconomic environment within census tracts.

The Statistical Analysis System (SAS Institute, 1985), was utilized to perform analysis of the data and determine the relationships of the variables. Tests were performed using hospital admission rates for respiratory disease as the dependent variable and air pollution measures and the Urban Pathology Index as independent variables.

Data Collection

Hospital Data

Hospital Selection. The four largest hospitals in Tulsa County were approached to assist in the data collection. Hospital admission records rather than patient's office visit records were chosen as the vehicle for data collection for the following reasons:

1) Hospitals treat the more seriously ill patients.
2) Hospitals singularly treat a more diverse socio-economic cross section of the public.
3) The collection of data by hospitals would be much simpler than gathering data from doctor's offices. (i.e., 4 hospitals versus 50 doctor's offices).
4) Hospital patient records should be standardized as compared to doctor patient records.
5) Hospital patient records are more likely to be computerized than doctor patient records.

Although the four largest hospitals in the county were approached, three were finally used as the data source. Computerization of patient records for three of the hospitals was complete by 1984. However, the fourth hospital had only begun storing patient records by magnetic tape in 1986. Retrieval of the data by any method other than computer would have been too time-consuming. In addition, the hospitals would not have been able to supply the personnel to assist in the collection. Therefore, only three of the hospitals were used as a source of patient data. Table III lists the hospitals in Tulsa County and their bed capacity.

TABLE III

TULSA COUNTY HOSPITALS AND PERCENT BED CAPACITY

Hospital	Beds	Percent Available Beds
*St. Francis	935	29
*St. John	723	23
*Hillcrest	596	19
OK Osteopathic	533	17
Doctor's	221	7
Broken Arrow	73	2
Memorial	54	2
Brookhaven	40	1

Source: 1985 Oklahoma Triennial State Health Plan. Oklahoma Health Planning Commission, July 1986.

*Hospitals utilized for present study

Hillcrest Medical Center, St. Francis Hospital, and St. John Medical Center produced the data needed by way of magnetic tape. The resultant hospitals represent 71% of available hospital beds and were the three largest hospitals in the county . John Cooper (1986), head of data processing at Hillcrest Medical Center, and Dr. Cassandra Jackson (1987), Health Facilitator at Tulsa University, felt that the three hospitals comprised an excellent socioeconomic cross section of the county residents. These hospitals seem to represent different geographic sections of the county.

Patient Variables. After letters of intent and purpose were sent to the participating hospitals to formally initiate the study, it was necessary to visit with administrative staff in the medical records department, quality conrol departments, and data processing departments. A common format for retrieving the data was devised by the data processing personnel at each hospital. Each hospital produced a tape that was then mounted on computer at Oklahoma State University. Table IV is a list of the variables that each admission record contained.

TABLE IV

HOSPITAL VARIABLES

Variables	
Date of admission	Sex
Patient address	Disease type
Age	Smoker/nonsmoker
Race	Occupation

The head of the Oklahoma University Medical Center in Tulsa and respiratory specialist, Dr. George Prothro, was consulted in order to construct a list of respiratory diseases that are most affected by air pollution. The diseases are recorded in Table V along with the International Classification of Disease Code (Ninth Revision) (ICD9 Code) (W.H.O., 1980). The ICD9 Code is the international standard for reference to diseases.

TABLE V

RESPIRATORY DISEASES MOST AFFECTED BY AIR POLLUTION

Disease Type	ICD9 Code
Acute bronchitis	466.0
Chronic bronchitis	491.0
	491.1
	491.2
	491.8
	491.9
Emphysema	492.0
	492.8
Malignant neoplasm of the lung	162.3
	162.4
	162.5
	162.8
	162.9

Source: World Health Organization, 1980. Commission on Professional and Hospital Activities. Ann Arbor: Edwards Bros., Inc.

The ICD9 Code was employed in the program to identify and extract from the records those patients with respiratory disease. Patients are admitted with a primary, secondary, and tertiary diagnoses. Dr. Prothro suggested that at least a secondary diagnosis with one of the four types of identified respiratory disease be retrieved from the data. The secondary diagnosis is often the precursor of the primary diagnosis and thus a vital cause of the patient's immediate illness. The computer program scanned the patient files and selected all patients with a primary or secondary diagnosis fitting any of the ICD9 Codes listed in Table V. The resultant respiratory data sets from the three hospitals produced over 3500 hospital admission records for the two years.

<u>Acute and Chronic Bronchitis</u>. The literature review indicated that bronchitis is an excellent indicator of the presence of air pollution at any given time. The presence of emphysema and lung cancer in a given area may indicate that there is a problem with air quality, however, it takes longer for such diseases to develop. It would, therefore, seem expedient to study bronchitis where cause and effect might be more temporally connected. That is, if air quality data were available for a period of several decades previous to diagnosed lung cancer, it would be justifiable to research the relationship of air pollution to lung cancer. Stations monitoring air pollution sources were not operable until the 1970s. Moreover, Tulsa's industrial scene changed

dramatically between 1970 and 1980 because of the closing of many oil refineries. The closing of these refineries has lessened the pollution emissions considerably. This fact alone would make a long-term study problematic even if appropriate hospital records had been available. The decision was therefore made to exclude lung cancer and emphysema from the study and concentrate on acute and chronic bronchitis. The resulting data included 849 observations of acute and chronic bronchitis.

Patient Addresses. The hospital data included individual addresses with zip codes to indicate place of residence. In order to analyze the data at a fine scale, the addresses were assigned to census tracts as observation units. The Government Base Files (GBF) (Kreps, 1977) were acquired from the Oklahoma State Highway Department. These files were created by the Census Bureau to assign individual addresses to census tracts. The GBF computer program was used to sort the listings of addresses of the hospital patients and assigned each to a census tract.

Because of some discrepencies on the hospital tapes--misspelled street names, rural route numbers without a specific street number, and other similar problems--it was necessary to assign approximately 40% of the tracts manually. This was accomplished by a street code book and large scale maps of city streets within the county. Approximately 90% of the patient addresses were thus reliably assigned census tract numbers.

The data were sorted by addresses and it was possible to identify patients admitted more than once for treatment. The decision was made to eliminate all but one visit to the hospital by each patient. This decision seemed logical and other studies were found not to use multiple admissions for each patient when researching spatial patterns.

Age of Patient. The present study used records of patients who were over the age of 45 when admitted to the hospital. This decision was based on much previous research as indicated in the literature review section of this thesis. In so doing, the study reduced the outside effect of the distribution of ages that is usually present in cities. The resultant rates should, therefore, be attributable only to environmental factors.

Admission Rates. The rates were determined by use of a location quotient (Rooney, 1974; Alexander, 1966). The total number of people who were admitted to the three Tulsa hospitals in 1984 and 1985 for acute and chronic bronchitis and were 45 years of age and older was divided by the number of people in the county over the age of 45 (Equation 1). This calculation produced a standard for the county, where 6.19 respiratory disease patients per census tract were expected.

$$\text{County Standard Value} = \frac{\text{County respiratory sufferers} \geq \text{age } 45}{\text{County population} \geq \text{age } 45} = \frac{849}{137{,}107} = 6.19 \qquad (1)$$

The number of victims of bronchitis over the age of 45 per census tract was divided by the number of residents in the tract over the age of 45 (Equation 2). The calculation of this equation produced a crude rate per 1000 residents of each census tract.

$$\text{Census Tract} = \frac{\text{Census tract respiratory sufferers} \geq \text{age } 45}{\text{Census tract population} \geq \text{age } 45} \times 1000 \qquad (2)$$

When the tract values are divided by the county standard, the expected value should be 1.00 (Equation 3). Any tract having a value over 1.00 would be expected to be linked to areas having poor air quality. Likewise, numbers below 1.00 could be associated with better air quality. Table VI lists the crude rate and per capita (location quotient) rate of disease by census tract. The rates can be compared with the census tract map in the back of this thesis.

$$\text{Expected Value} = \frac{\text{Census tract Value}}{\text{County Standard Index Value}} \qquad (3)$$

Air Quality Data

Whereas this study addresses only outside ambient air pollution and its proximity to place of residence of respiratory patients, other forms of pollution do exist. Personal pollution includes smoking, and occupational exposure, which is defined as the exposure of persons to pollution in their working place and community. In addition, indoor air pollution has been recently defined as a pollution type and includes household sprays, paint, varnish and certain types

TABLE VI

CRUDE RATE AND PER CAPITA RATE OF ACUTE AND CHRONIC BRONCHITIS BY CENSUS TRACT

Census Tract	Crude Rate	Per Cap	Census Tract	Crude Rate	Per Cap	Census Tract	Crude Rate	Per Cap
1	2.22	0.35	43.02	5.90	0.95	72	7.84	1.27
2	6.06	0.98	44	5.49	0.88	73.03	4.63	0.74
3	9.42	1.52	45	7.68	1.24	73.04	6.06	0.98
4	6.31	1.02	46	2.97	0.48	73.05	17.49	2.82
5	6.02	0.97	47	7.09	1.15	73.06	7.32	1.18
6	3.47	0.56	48	5.97	0.96	73.07	4.71	0.76
7	6.96	1.12	49	13.49	2.18	73.08	2.88	0.47
8	0.00	0.00	50.01	3.64	0.58	74.01	5.46	0.88
9	10.16	1.64	50.02	6.29	1.01	74.02	8.84	1.43
10	5.53	0.89	51	3.08	0.50	74.03	2.22	0.36
12	8.93	1.44	52	7.52	1.21	75.02	8.24	1.33
13	7.91	1.28	53	6.16	1.00	75.03	8.47	1.36
14	7.19	1.16	54	2.36	0.38	75.04	2.17	0.35
15	8.12	1.31	55	4.93	0.80	75.05	5.62	0.91
16	7.86	1.27	56	7.75	1.25	76.01	14.38	2.32
17	8.91	1.44	57	7.51	1.21	76.02	6.21	1.00
18	4.61	0.74	58.01	1.02	0.16	76.03	8.07	1.30
19	4.68	0.75	58.02	2.35	0.39	76.04	9.78	1.58
20	5.79	0.93	59	15.13	2.47	76.05	9.30	1.50
21	7.21	1.16	60	4.92	0.79	76.06	9.19	1.48
22	6.12	0.99	61	6.36	1.03	76.07	4.36	0.70
23	24.05	3.89	62	6.66	1.08	77	6.64	1.07
24	5.65	0.91	63.01	9.31	1.50	78	3.20	0.52
25	11.85	1.91	63.02	23.25	3.76	79	3.52	0.57
26	9.26	1.49	64.01	8.58	1.39	80.01	8.78	1.42
27	12.32	1.99	64.02	2.40	0.39	80.02	2.95	0.16
28	6.80	1.09	65.01	3.93	0.63	81	5.05	0.82
29	4.11	0.66	65.03	6.08	0.98	82	2.30	0.37
30	6.71	1.08	65.04	3.51	0.56	83	2.12	0.34
31	9.11	1.47	66	6.25	1.01	84	2.60	0.42
32	16.37	2.64	67.01	3.92	0.63	85.01	0.00	0.00
33	7.49	1.21	67.03	2.31	0.37	85.02	2.94	0.47
34	6.80	1.10	67.04	6.66	1.08	86	7.30	1.18
35	15.76	2.54	68.01	12.45	2.01	87	10.03	1.62
36	7.09	1.15	68.02	3.35	0.54	88	4.68	0.76
37	8.52	1.38	69.01	7.54	1.22	89	3.41	0.55
38	12.30	2.00	69.02	7.15	1.16	90.02	8.46	1.37
39	7.56	1.22	69.03	3.77	0.61	90.03	8.94	1.44
40	5.66	0.91	69.04	0.00	0.00	90.04	1.72	0.28
41.01	2.23	0.36	69.05	5.34	0.86	90.05	1.48	0.23
41.02	4.92	0.79	70	6.58	1.06	91.01	1.30	0.21
42	9.04	1.46	71.01	4.22	0.68	91.02	0.67	0.11
43.01	13.32	2.15	71.02	4.75	0.77	91.03	8.32	1.34

of building materials that contain harmful substances such as formaldahyde (Sherman, Grimsrud, 1982).

Roger, Randolf, the head of the Air Quality Division of the Tulsa City-County Health Department was contacted and meetings were scheduled with key personnel in the Air Quality Department. The Health Department cooperated with the research by providing the following:

1) state and local annual reports
2) air quality standard reports
3) computerized tapes of air quality as recorded by the 15 monitoring stations situated throughout the county (Figure 2) (Table VI).
4) lists and addresses of major sources of pollution
5) air quality library materials
6) individual tours of the monitoring stations where air quality data are collected.

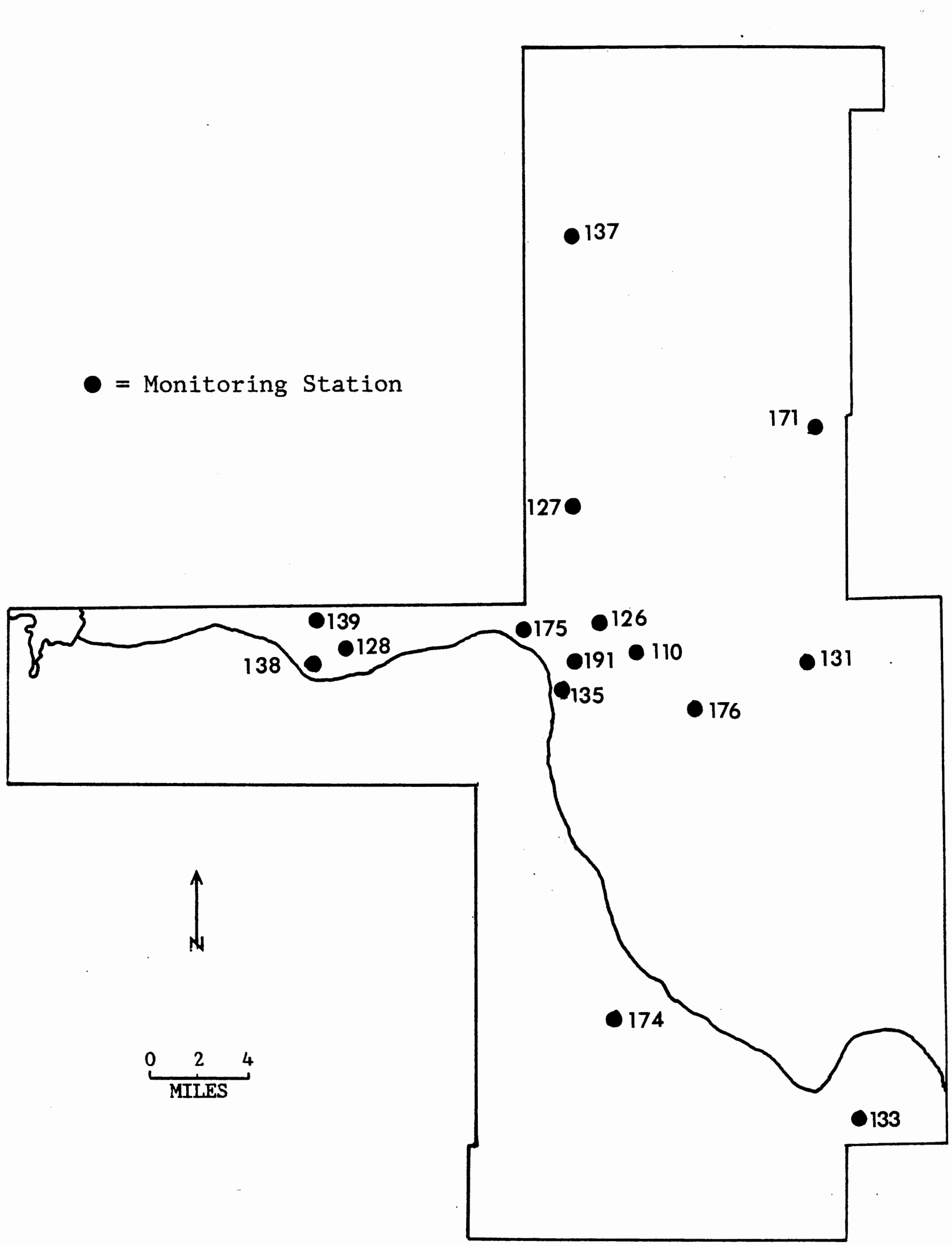
Monitoring Stations. There are 15 monitoring stations in Tulsa County that monitor pollutants designated as harmful and the EPA has set standards for their emissions. Types of pollutants and station numbers are listed in Table VII. The station's placement are displayed in Figure 4. The annual arithmetic mean for years 1984 and 1985 for total suspended particulates were utilized to test H_b.

TABLE VII

MONITORING STATIONS AND POLLUTANTS MEASURED

Site No.	Address	Pollutant Measured
110	4616 E. 15th St.	TSP
126	601 S. Lewis Ave.	CO
127	1326 Mohawk Blvd.	O_3, NO_2
128	306 E. Broadway Sand Springs, OK	TSP
131	11707 E. 31st St. S.	TSP
133	1.5 miles south of Leonard, OK	TSP
135	1023 W. 23rd ST. S.	SO_2
137	1100 S. Osage Dr. Skiatook, Ok	O_3
138	200 S. Walnut, Sand Springs, OK	TSP
139	1200 North Cleveland Sand Springs, OK	TSP
171	6525 B, 129th E. Ave.	TSP
174	502 E. 144th Pl. S.	O_3, NO_2,
175	1710 W. Charles Page Blvd.	SO_2
176	3613 S. Hudson Ave.	TSP, Lead
191	1413 S. Cincinnati	TSP, CO, NO_2

Source: Tulsa City County Health Department <u>1985 Annual Report</u>



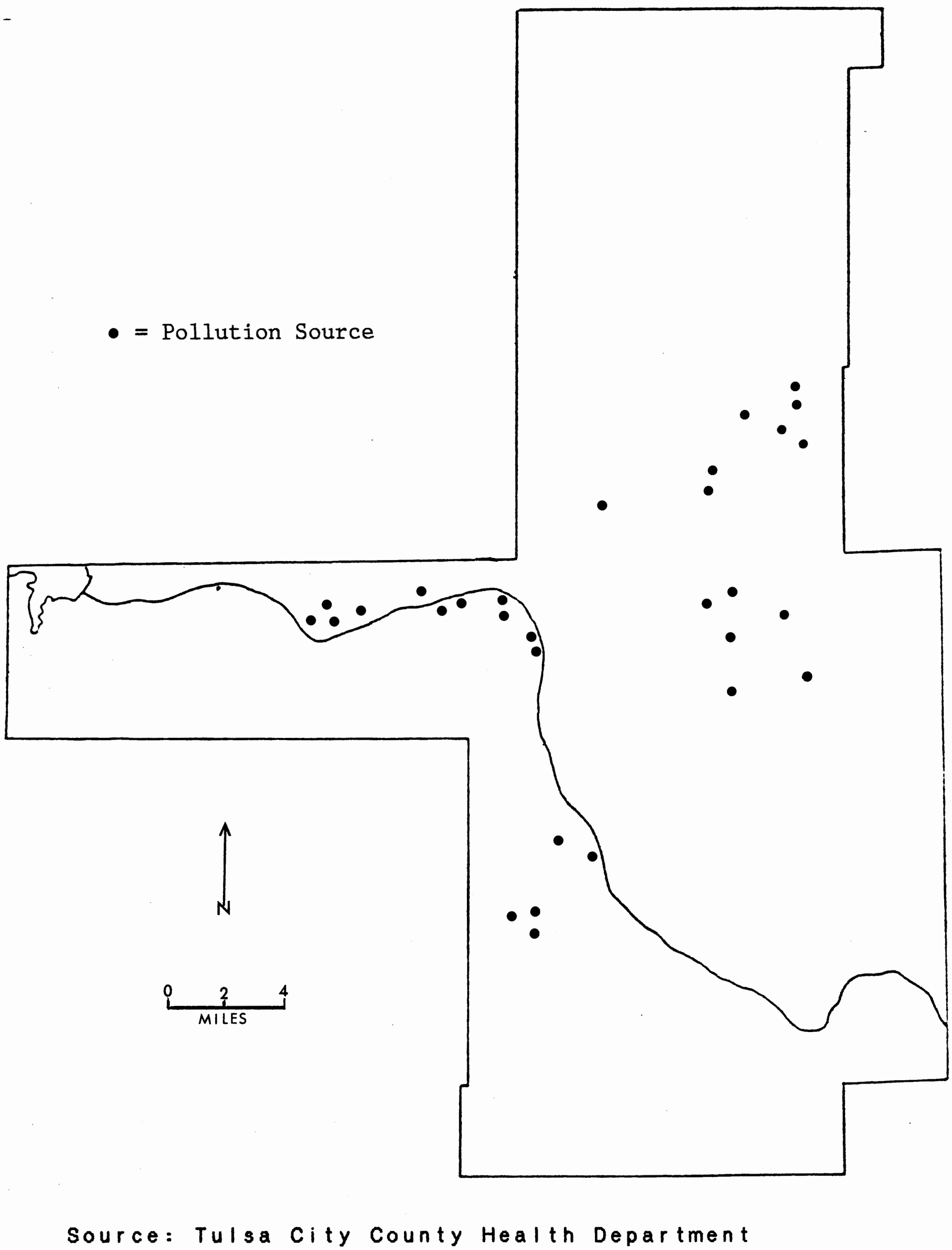
Source: Tulsa City County Health Department
1985 Annual Report

Figure 4. Base map of Tulsa County indicating locations of pollution monitoring control stations.

Pollution Sources. A list of addresses of major sources of pollution within the county was supplied by the The Tulsa City-County Health Department. To test H_a, these addresses were plotted on a base map (See Figure 5). The accumulative distances were measured from the areal center of each tract to the three closest sources of pollution.

Census Data

Urban Pathology Index. Jones and Eyles (1977) have measured the pathology of a city by using a process called factorial ecology. This process utilizes a wide range of demographic, socioeconomic and housing information. They state, "...it will be possible to account for the manifold variation in neighborhood characteristics in terms of a much smaller number of underlying constructs." Jones and Eyles (1977) also indicate that census variables can be aggregated to create an index to function as a second independent variable to assess the socioeconomic environment of each census tract. Census data are numerous, therefore it is difficult to select what is relevant to any particular study. Factoral ecology has been applied in several other recent studies that use socioeconomic variables (Jones and Eyles 1977, Timms 1971, Harries, Stadler, Zdorkowski 1984). These variables are employed to create an index commonly referred to as an Urban Pathology Index (UPI). The UPI is most usually constructed from socioeconomic indicators depicting urban status within a designated area. Because the data for this research are based on census tracts, the



Source: Tulsa City County Health Department
1985 Annual Report

Figure 5. Base map of Tulsa County indicating locations of the major sources of pollution utilized in measuring H_a

1980 Census provided the data base for the index. The advantage of an index is that several indicators can be aggregated to compose one parameter that can be statistically tested against the other variables.

Three variables compose the UPI as follows: percent substandard housing, percent black, and median household income. The UPI was then created as a sum of the three variables that were rank ordered (Table VIII). The income ranks were reversed so that census tracts with high incomes would have a low rank. These would then correlate with census tracts that had a low percentage of blacks and tracts that had a low percentage of substandard housing. Those census tracts having a high rank were considered to have a high social pathology and low rankings had a low social pathology.

There are many ways to measure substandard housing. Common indicators are overcrowding per room and inadequate plumbing. To satisfy that there were no differences in the two measures, two indices were created; one utilizing overcrowding, the other inadequate plumbing. A Spearman's Correlation test was utilized to determine if these two indices were highly correlated. The test produced a correlation coefficient of .91. Inadequate plumbing is most commonly used as the substandard housing measure, and because the two measures were so closely related, it was therefore decided that inadequate pumbing would be utilized as the measure of substandard housing for this research.

TABLE VIII

URBAN PATHOLOGY INDEX BY CENSUS TRACT
BASED ON SOCIOECONOMIC VARIABLES

Census Tract	UPI	Census Tract	UPI	Census Tract	UPI
1.00	307.0	43.02	57.0	72.00	123.0
2.00	345.0	44.00	137.0	73.03	144.0
3.00	318.0	45.00	40.0	73.04	155.0
4.00	305.0	46.00	338.0	73.05	158.0
5.00	375.0	47.00	159.0	73.06	234.0
6.00	350.0	48.00	168.5	73.07	225.5
7.00	337.0	49.00	246.5	73.08	168.0
8.00	302.5	50.01	186.0	74.01	190.0
9.00	360.0	50.02	172.0	74.02	165.0
10.00	318.0	51.00	41.0	74.03	135.0
12.00	346.0	52.00	123.0	75.02	102.0
13.00	312.0	53.00	85.5	75.03	154.5
14.00	260.0	54.00	197.0	75.04	140.5
15.00	217.0	55.00	186.5	75.05	117.0
16.00	205.0	56.00	230.5	76.01	265.0
17.00	174.0	57.00	334.0	76.02	109.0
18.00	148.5	58.01	153.5	76.03	53.0
19.00	169.0	58.02	145.0	76.04	71.5
20.00	237.0	59.00	272.0	76.05	81.0
21.00	339.0	60.00	180.0	76.06	81.0
22.00	233.0	61.00	277.0	76.07	114.0
23.00	304.0	62.00	365.0	77.00	217.5
24.00	286.0	63.01	98.5	78.00	235.0
25.00	285.0	63.02	327.0	79.00	360.0
26.00	301.0	64.01	235.0	80.01	373.0
27.00	262.0	64.02	174.5	80.02	338.0
28.00	254.0	65.01	267.0	81.00	234.5
29.00	209.5	65.03	106.5	82.00	233.0
30.00	207.5	65.04	233.0	83.00	208.0
31.00	205.0	66.00	169.5	84.00	66.0
32.00	179.0	67.01	355.0	85.01	133.0
33.00	153.5	67.03	171.0	85.02	41.0
34.00	269.0	67.04	108.0	86.00	126.0
35.00	178.0	68.01	201.0	87.00	89.0
36.00	79.5	68.02	179.0	88.00	318.5
37.00	84.5	69.01	31.5	89.00	160.5
38.00	139.0	69.02	13.5	90.02	185.0
39.00	125.5	69.03	59.0	90.03	225.0
40.00	120.5	69.04	97.0	90.04	219.0
41.01	7.5	69.05	130.0	90.05	154.0
41.02	58.0	70.00	192.5	91.01	347.0
42.00	38.5	71.01	188.5	91.02	293.0
43.01	42.5	71.02	158.0	91.03	277.0

Variables=percent black, median household income, and inadequate plumbing

The UPI was tested against the pollution data to determine if poor socioeconomic conditions are significantly correlated with pollution. Statistical tests analysis of variance (ANOVA), step-wise regression, Pearson correlation coefficient, and chi-square were employed. The UPI can be compared with the census tract map included in the inside back cover of this thesis.

Data Manipulation

Subhypotheses H_a and H_b

Two hypotheses were tested to determine if one might be a more better measure of the incidence of respiratory disease. The two hypotheses are restated here for clarification:

H_a: The rate of patients with respiratory illness admitted to hospitals decreases with distance from major pollution sources.

H_b: The rate of patients with respiratory illness admitted to hospitals are relatively high when monitered air pollution levels are relatively high in their residential area.

Testing H_a. Pollution sources are classified as either an A-1 or an A-2 source. An A-1 polluter is designated as "any stationary pollution source whose actual emissions or potential emissions while operating at the design capacity are over 100 ton of particulates per year." An A-2 polluter is designated as "any stationary pollution source whose uncontrolled emissions, operating at the design capacity, are equal to or exceed 100 tons per year for any regulated pollutant but whose actual emissions are less than 100 tons per year" (Tulsa City-County Health Department, 1985). In order to test H_a, it was necessary to create a measure of air pollution by census tract based on distance to major sources of pollution. The pollution measure per census tract was created in the following manner:

1) x, y coordinates were established for the locations of each major polluter in the county.
2) x, y coordinates were established for the areal center locations for all 129 census tracts.
3) A program was utilized to measure the cumulative distances from the center of each census tract to the three closest sources of pollution in the upwind direction. The average wind blows from the south, southeast in Tulsa County. A stipulation in the program provided for pollution sources that were in the same census tract to be included as one of the three pollution sources.
4) A second SAS program was utilized to measure the cumulative distances of the three closest pollutors regardless of the wind direction.

The above steps, produced a pollution measure by tract (See Table IX). The resultant numbers (measure of distance) displayed in Table IX do not represent miles. They were de-ised from a base map using x, y coordinates. The distance measure was statistically tested against the hospital pat-ient data and the UPI. Table IX can be compared with the census tract map found inside the back cover of this thesis.

TABLE IX

POLLUTION MEASURES AGGREGATED BY
CUMULATIVE DISTANCES
BY CENSUS TRACT

	Measure			Measure			Measure	
Tract	1	2	Tract	1	2	Tract	1	2
1	2.88	3.13	43.02	2.87	7.45	72	2.50	2.96
2	4.55	4.55	44	1.85	7.52	73.02	2.50	2.96
3	3.78	4.63	45	1.68	1.68	73.03	5.66	6.20
4	4.31	4.60	46	1.00	1.27	73.04	4.92	4.92
5	4.73	4.74	47	2.74	7.10	73.05	4.13	6.38
6	4.19	4.19	48	2.70	7.15	73.06	5.22	7.47
7	4.13	4.13	49	1.44	1.44	73.07	6.58	6.64
8	4.14	4.14	50.01	2.70	7.72	73.08	7.77	9.11
9	3.08	3.87	50.02	3.48	8.13	74.01	8.97	17.87
10	3.03	4.16	51	4.32	8.79	74.02	9.72	17.37
12	3.07	3.07	52	3.67	8.83	74.03	6.35	13.40
13	3.07	4.60	53	1.54	5.33	75.02	12.07	16.46
14	3.95	3.95	54	16.93	16.93	75.03	10.58	17.00
15	3.73	4.83	55	19.19	19.19	75.04	11.87	17.31
16	2.82	4.24	56	13.28	13.28	75.05	8.05	12.80
17	2.42	2.77	57	6.79	6.79	76.01	5.28	6.42
18	2.93	3.19	58.01	5.09	5.10	76.02	5.62	7.03
19	3.01	3.55	58.02	7.94	7.94	76.03	5.72	7.41
20	3.36	4.05	59	.94	.94	76.04	5.47	9.91
21	3.28	3.75	60	2.38	4.35	76.05	5.89	9.03
22	3.56	4.34	61	2.96	2.96	76.06	8.12	10.88
23	3.04	3.62	62	5.55	5.55	76.07	5.29	7.18
24	2.80	3.46	63.01	2.03	2.03	77	4.77	4.77
25	2.51	2.91	63.02	.44	.44	78	13.14	0.00
26	2.13	2.13	64.01	.98	.98	79	8.14	8.14
27	2.11	2.11	64.02	6.36	6.36	80.01	5.83	5.83
28	2.11	2.11	65.01	3.37	9.95	80.02	7.23	7.23
29	3.09	3.09	65.03	3.90	12.21	81	2.04	5.44
30	2.00	2.00	65.04	8.83	16.76	82	2.71	5.08
31	1.54	1.54	66	1.73	1.73	83	3.23	3.79
32	2.23	2.23	67.01	3.86	8.61	84	1.98	5.69
33	3.01	3.08	67.03	3.14	3.14	85.01	3.07	5.90
34	3.09	3.47	67.04	3.70	3.70	85.02	2.92	5.68
35	3.29	3.52	68.01	4.01	8.33	86	3.21	8.82
36	3.36	3.58	68.02	4.58	8.35	87	5.19	8.04
37	2.48	3.71	69.01	5.03	7.91	88	2.22	2.23
38	1.68	1.68	69.02	4.59	7.94	89	4.05	4.90
39	2.43	4.93	69.03	4.31	8.09	90.02	5.78	10.94
40	2.89	5.90	69.04	3.84	8.81	90.03	6.03	10.12
41.01	3.84	7.44	69.05	3.21	8.91	90.04	4.06	6.44
41.02	3.49	4.32	70.	2.32	6.02	90.05	7.00	9.11
42	3.34	4.18	71.01	2.15	4.29	91.01	10.12	10.12
43.01	2.77	2.77	71.02	3.63	3.63	91.02	8.00	8.00

1 = Measure of cumulative distances upwind of areal center of census tract to three closest sources of pollution. (If source was in same tract, regardless of wind direction, it was included in the measure.)

2 = Measured cumulative distances from areal center of census tract to three closest sources of pollution regardless of wind direction.

Testing H_b. The data for testing H_b were processed in the following manner:

1) The average total suspended particulate (TSP) data were calculated for 1984 and 1985 in micro grams per cubic meter at each of nine monitoring control stations.

2) An isoline map was constructed by interpolating the TSP data on to a census tract base map of Tulsa County.

3) The census tract was assigned the value of the gradient that fell directly over the areal center of the census tract.

In Table X a list of census tracts are displayed along with the TSP values that were assigned to each tract. The higher rates indicate census tracts that were, on the annual average, exposed to higher rates of pollution than a neighboring census tract in a lower gradient. These pollution rates were tested as the independent variable against the hospital disease rates

Patient Variables

The patient variables that were extracted from the hospital data were employed in the statistical testing of the main hypothesis. Only patients over the age of 45 were observed, and the percent of blacks was determined for each census tract. Jackson (1986a) has determined that white males comprise 86% of the acute and chronic pulmonary deaths for residents in the United States. Whether or not the

TABLE X

POLLUTION MEASURES AS INTERPOLATED BY MONITORING CONTROL STATIONS (GRAMS PER CUBIC METER) BY CENSUS TRACT

Tract	Measure	Tract	Measure	Tract	Measure
1	63	43.02	56	72	63
2	65	44	56	73.03	62
3	65	45	60	73.04	62
4	65	46	60	73.05	61
5	65	47	57	73.06	61
6	65	48	57	73.07	60
7	65	49	60	73.08	59
8	65	50.01	57	74.01	57
9	65	50.02	57	74.02	56
10	65	51	56	74.03	56
12	65	52	59	75.02	52
13	65	53	60	75.03	55
14	65	54	58	75.04	54
15	64	55	60	75.05	56
16	63	56	65	76.01	56
17	60	57	65	76.02	56
18	60	58.01	63	76.03	56
19	60	58.02	62	76.04	56
20	62	59	66	76.05	56
21	61	60	63	76.06	53
22	63	61	62	76.07	52
23	63	62	63	77	45
24	63	63.01	70	78	45
25	64	63.02	75	79	65
26	65	64.01	66	80.01	67
27	65	64.02	55	80.02	66
28	65	65.01	55	81	64
29	65	65.03	55	82	64
30	65	65.04	50	83	63
31	60	66	63	84	61
32	63	67.01	55	85.01	62
33	60	67.03	50	85.02	61
34	63	67.04	50	86	59
35	63	68.01	57	87	56
36	63	68.02	57	88	70
37	63	69.01	57	89	65
38	63	69.02	57	90.02	59
39	60	69.03	58	90.03	59
40	60	69.04	60	90.04	63
41.01	55	69.05	60	90.05	60
41.02	60	70	60	91.01	65
42	62	71.01	62	91.02	67
43.01	61	71.02	62	91.03	67

patient smokes was addressed along with the other hospital variables, proximity to sources of pollution, and pollution rates to determine the incidence of respiratory disease in each census tract.

Occupation of patient was obtained in the hospital data. However, lack of complete information and nonstandardized occupation records made it impossible to discern whether the patient worked in an office or in a more hazardous position within a given company as usually only the company name was given for occupation. Therefore controlling for the occupation of the patient was impossible.

All possible causes of disease would be impossible to collect. For example, lifestyle, nutrition, genetic and ancesterol data are not available. Therefore, 100% explanation of the variables is not expected.

Maps

The Atlas Mapping Package (1986) was employed to create a boundry file for Tulsa County. Using a Lotus 2.01 (1985) program, a spread sheet was created to tabulate the UPI indices, the hospital rates, the cumulative distance rates, and the interpolated pollution data. The Atlas Mapping Package created choropleth maps from the spread sheet so that the data could be visually inspected.

These maps are incorporated in Chapter V of this thesis. They are utilized to explain the spatial distribution of the variables and support the final analysis of the present research.

Conclusion

The data defined in this chapter were aggregated and manipulated by the Statistical Analysis System (SAS). The independent variables, urban pathology and the pollution rates were created and put into form for testing for the hypotheses, H_a and H_b. The analyses of the statistical testing are discussed in the following chapters.

CHAPTER V

DATA ANALYSIS

Overview

The purpose of this chapter is to examine the data collected to support the following main hypothesis:

> Spatial correspondence exists between places of residence of respiratory patients admitted to hospitals and the presence of poor ambient air quality.

The data analysis included inspection of the distribution of the dependent variables (hospital rates) and the independent variables (pollution and UPI rates). Statistical testing follows the explanation of the mapped data.

Qualatative Analysis of Mapped Data

A fold-out map, Figure 12, is placed in a pocket on the last page of this thesis. The fold-out map will assist the understanding of the choropleth maps as well as the text material.

Crude Rate of Acute and Chronic Bronchitis

Figure 6 represents the rate of acute and chronic bronchitis employed as the dependent variable in this study.

Two legends are displayed, a per capita index that utilizes a location quotient and a crude rate of disease (per 1000 residents per census tract). The expected value of the location quotient is "1". The "1" represents the county standard of 6.19 sufferers of respiratory distress per 1000 residents in each census tract. Values above "1" indicate problematic areas where poor environmental conditions may exist. Each of the rates employ populations of only people over the age of 45. When these rates are broken down by quintiles, the maps are identical. Therefore, only one map is shown here with the two different legends.

Figure 6 indicates that the highest disease rates (those categories above "1") are concentrated near the Central Business District (CBD), tract 25, with a per capita index of 1.44-3.89. Refer to Table VI for a list of indices by census tract. The high rates also tend to follow the Arkansas River near the industrial pollution sites, starting from the west in the Sand Springs area, tracts 63.01, 63.02, 64.01, and 88. In this area north and south of the river and west of the CBD, there are valley walls that tend to confine pollution (Figure 3). Situated along this valley is a major steel producing firm. This firm is out of compliance with the EPA and is producing over the standard allowable TSP per year (Randolph, 1986). The steel company is eight miles west of Tulsa's CBD, located in Sand Springs (See Figure 5).

Pollution haze often persists along the river and around the CBD as a result of slow air movement and perhaps

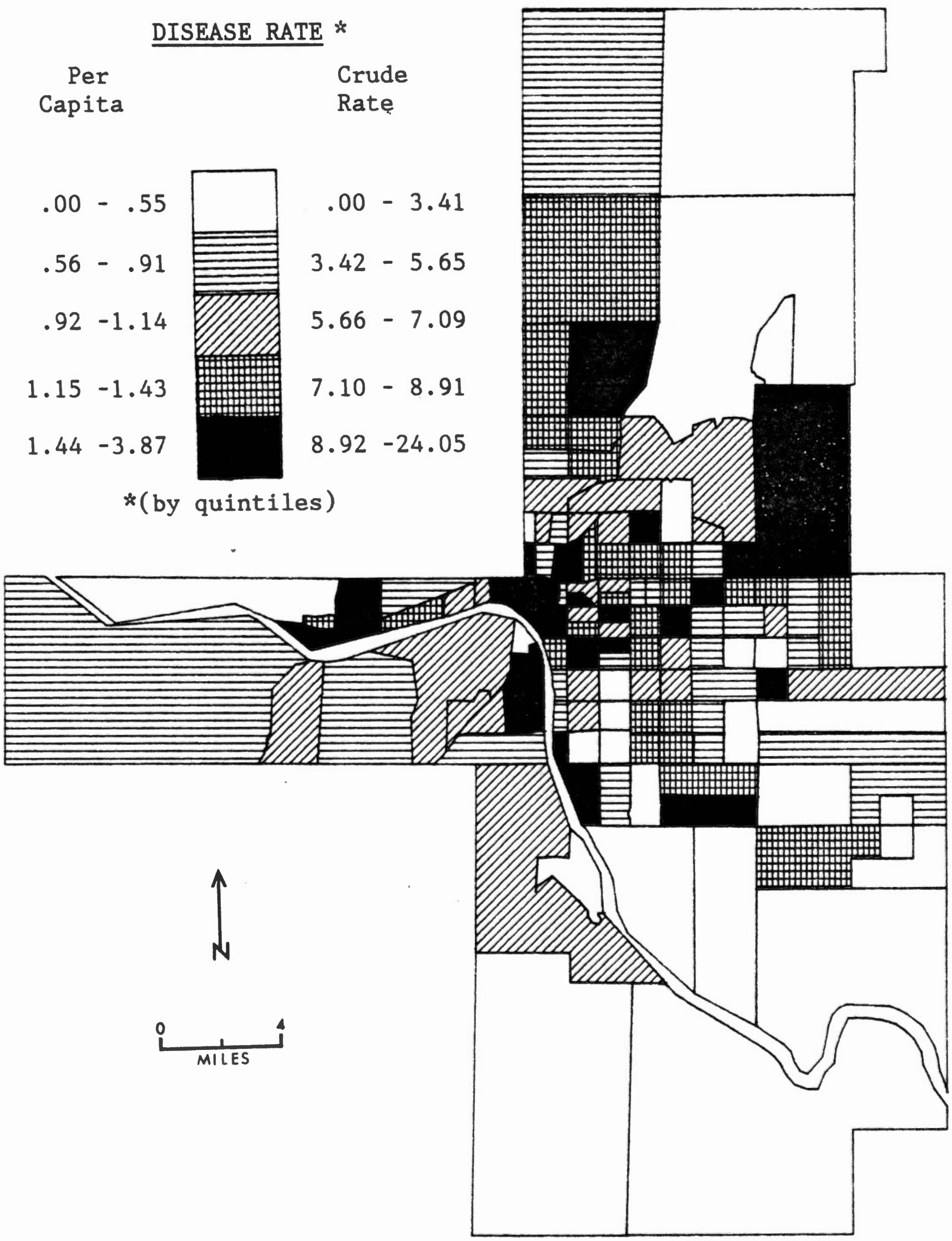


Figure 6. The crude rate of respiratory disease (Legend A), and a per capita index where "1" is the expected index (Legend B).

the presence of the valley walls. Other major pollutors occupy this belt to the west of Tulsa's downtown, namely fiberglass, glass, oil refineries and chemical companies (See Figure 5). Winds, or the lack thereof, channeled from the west between these valley walls may well be a contributing factor responsible for the high rates of disease that appear and then disperse out to the CBD. Much research has been contributed to epidemilogic studies concerning the effects of stagnant air and pollution on the human respiratory system.

As the river and its valley walls bend down to the south, high rates tend to follow where sources are nearby, (tracts 49, 6801, 76.01). High rates of incidence also appear toward the north and east of the city. Tracts 91.02 and 91.03 indicate high disease rates and are surrounded by tracts that have lesser rates of disease, but well above the expected value of "1". These tracts are downwind from most sources of pollution within the county. In Figure 7, this entire area is indicated as having high UPI.

Tracts 54, 55, 56, and 58.02 are large tracts, rural areas, and without sources of pollution. Tract 51 indicates a high disease rate. Pollution sources here include three limestone rock crusher plants. Tract 71.02 and adjacent tracts indicate high disease rates. There is a chemical plant in tract 71.02. There are other tracts where high rates are indicated within the county but where pollution sources are not indicated. It must be noted that Figure 5 does not contain all major sources of pollution within the county. The Tulsa City-County Health Department list 116 pollution sources within the county. The present study mapped only the A-1 and A-2 source polluters defined in Chapter 3. The remainder of the pollution sources are Class B sources. These sources are defined as any stationary source whose uncontrolled emissions are less than 100 tons per year. There are appoximately 85 Class B pollution sites in Tulsa County and they were not incorporated in this study. Class B will have some effect on communities around their sites. It was felt that significant patterns of pollution could be obtained without the mapping of these polluters. Other factors may be present within the area causing the high, unaccounted for rates such as high traffic areas with excessive amounts of auto exhaust.

Tracts to the south of the city, 77, 78, 75.02, 76.06, 76.07, are without industrial pollution sources. These tracts are south of major sources of pollution and are mostly rural. It is noteworthy that the per capita disease rate is negligible here, (0-.55). However, the rural tracts that border the southern county line on the western arm of the county show indices of disease, some above the expected "1" value. Creek county fits under this arm of the county to the south. The city of Sapulpa is located here and although the Tulsa City-County Health Department data does not extend beyond the county boundaries, there are some major industies in Sapulpa. Therefore, the hospital admission pattern in this part of the county might be partially explainable.

Urban Pathology Index

Figure 7 was constructed using an Urban Pathology Index (UPI) which included percent black, median income, and percent of substandard plumbing in a census tract as explained in Chapter 4. The UPI was employed as an independent variable to control for high and low social status census tracts within the study. Quintiles were employed as classes to display the data.

The UPI map indicates similarities as well as differences to the per capita rate of disease map, Figure 6. The greatest UPI indices are clustered in, around, and north of the CBD. This general area is known as an area of poverty in the city of Tulsa (Metropolitan Human Services Commission, 1984). Some of the high indices are adjacent to the river channel near the industrial pollution sites. Research indicates that the poor tend to live in the more polluted areas of the city (Gunville, 1977; Stadler, 1979). Most of these homes are older and many without air conditioning. It is probable that in the summer months the windows may be open as relatively few may be able to afford air conditioning. Thus, relatively high levels of air pollution might enter these homes.

The south and west extremities of the county indicate the second highest level of UPI. A high UPI is expected here, as these areas are rural, and substandard housing is often equated with rural neighborhoods. The section of the

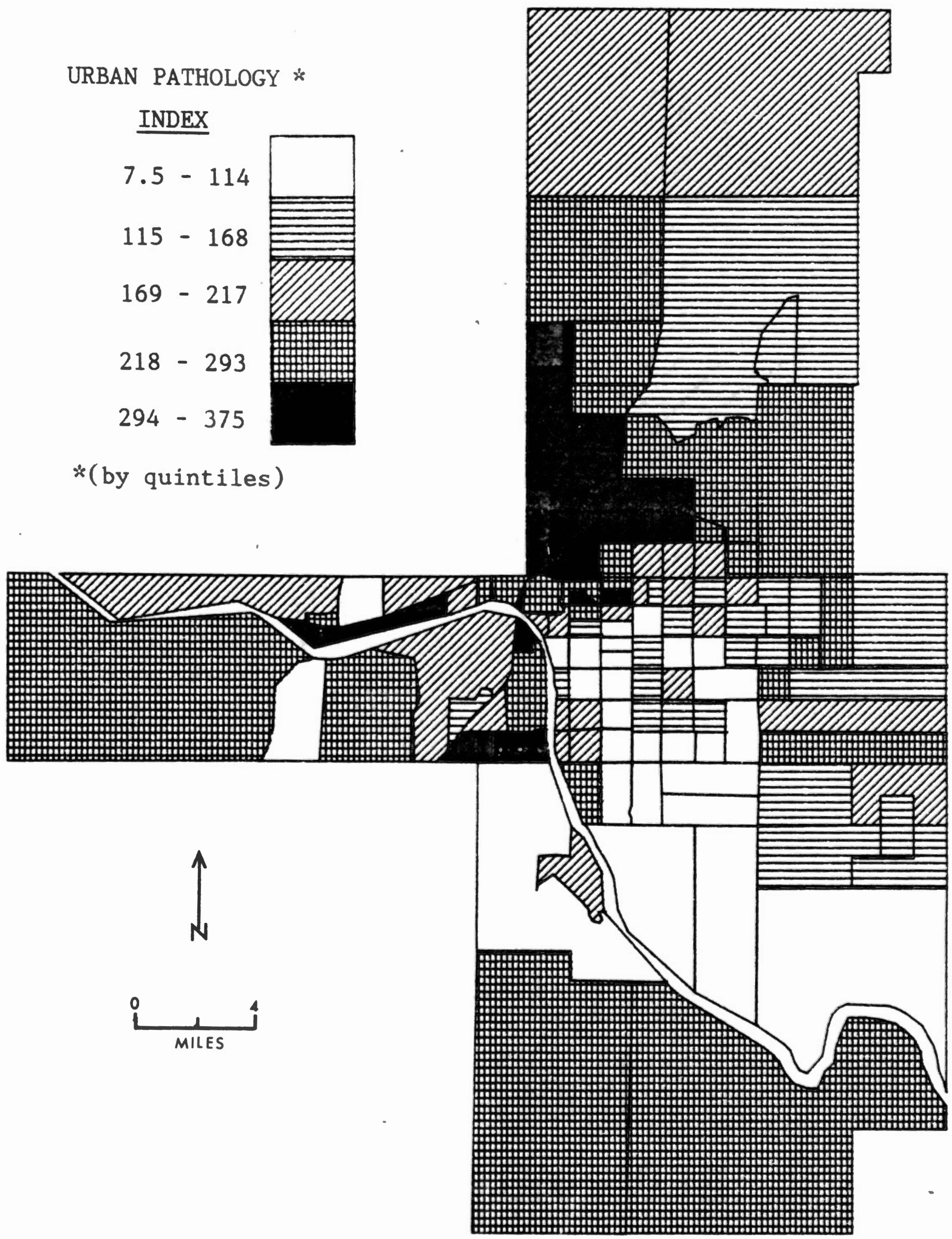


Figure 7. Urban Pathology Index by census tract utilizing percent black, median income, and insufficient plumbing.

county located just north of the Arkansas River in the southeast quadrant of the county is the most affluent section of the county and is characterized by low urban pathology.

Figures 6 and 7 do not look altogether alike. However there are important facts that should be noted here. The greatest percentages of poor live near to and north, or downwind of most sources of pollution (See Figure 5). Some census tracts that have high disease rates, correspond with the highest UPI. The second highest level of disease rate tends to correspond more with the UPI than the highest level of disease rate. This intense area of high UPI north of the CBD is served by a community outpatient hospital that is successfully serving the underprivileged. It is quite possible to assume that if these records were obtained, disease rates would be much greater than indicated by the three participating hospitals. However, it would be difficult to determine the severity of the outpatient visits as compared to the hospital admission records. The records, therefore, would not have been compatible with the present study.

Pollution Rates by Distance

Figures 8 and 9 were created by measuring distances from the centers of census tracts to the three closest sources of pollution; one in the upwind direction and the other measured the three closest sources of pollution, regardless of the wind direction. This second distance measure was modeled because winds normally flucuate and topography and north winter winds affect pollution plumes. It was postulated that this second measure might help to explain the incidence of respiratory disease. The pollution rates were created to support subhypothesis H_a, and were employed as independent variables. Figures 8 and 9 utilize quintiles to display the data by classes. The map legends indicate that the smaller the number, the shorter the distance from the tract to the sources of industrial pollution.

The annual average wind direction in Tulsa County is from the south southeast at ten miles per hour. Pollution stacks in the county are not tall. It is, therefore, expected that pollution plumes will be greater in tracts where the pollution is occurring and tracts adjacent to pollution sources.

Figures 8 and 9 are similar. Both maps portray the rural extremities at greater distance from pollution sources. The only exception, however, is noted in tract 77. There are several oil refinery tank farms in this tract. In examining the distance map measuring pollution sources regardless of wind direction, the classes of measurement tend to shift to a lower gradient of pollution in census tracts reading from south to north. This was, of course, the expected outcome of the model. Overall, one distance measure should be as accurate as the other, given the similarities of the two maps.

The distance maps (Figures 8 and 9) were compared to

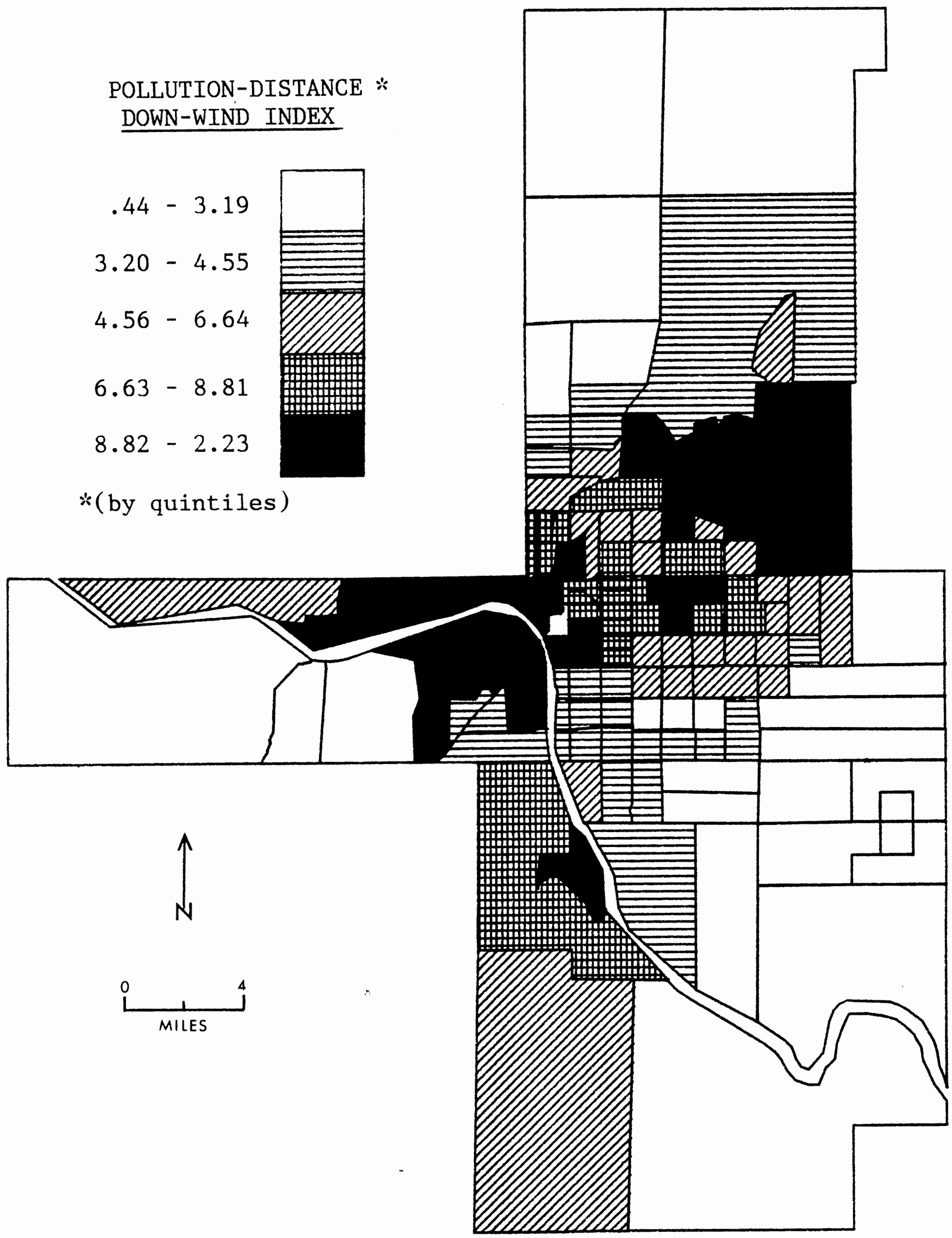


Figure 8. Distance measure from areal center of census tracts to three closest sources of pollution in the upwind direction in Tulsa County, Oklahoma.

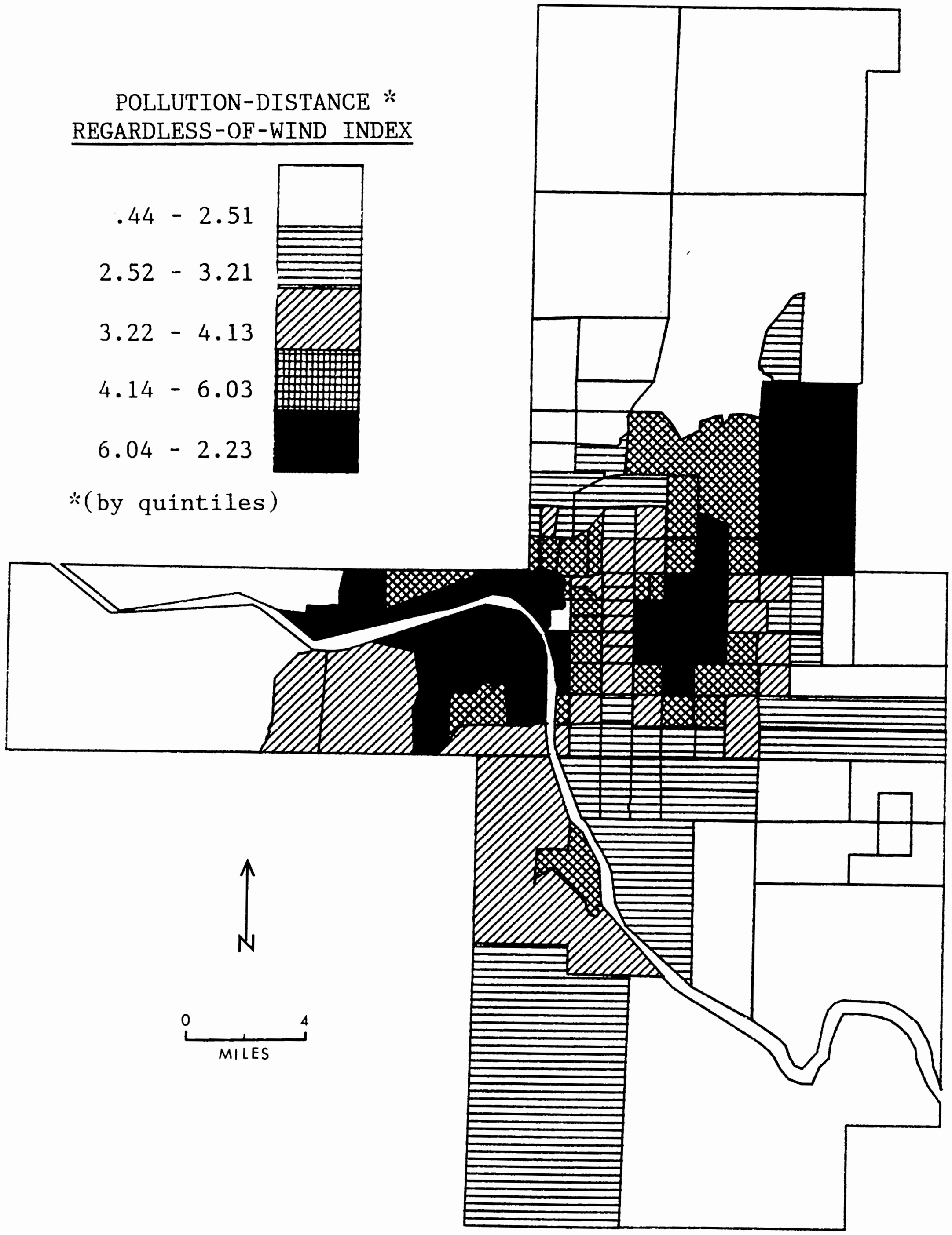


Figure 9. Distance measure from areal center of census tracts to three closest sources of pollution in Tulsa County, Oklahoma (regardless of wind direction)

the disease rate maps for similarity of phenomena. In addition, comparisons of Table IX listing the distances in x, y coordinate measures and the census tract map (Figure 12) were compared to draw conclusions about the data.

There are clusters of census tracts indicating nearby pollution sources along the Arkansas River. A steel mill, fiberglass plant, glass plant and a few oil refineries dominate tracts 64.01, 63.02, 63.01, 88, 30, 28, 66, and 49. The rock crusher plants appear to the east, tract 59, and the Tulsa Airport is in tract 61.

Figure 9 displays 11 tracts clustered in the center of the county that have pollution sources nearby. These tracts are small (1 mile square) tracts compared to other tracts where pollution is high. Because the areal center was used as a measure for distance to the sources of pollution, the impact of pollution sources affects several small tracts as opposed to larger areas where only one or two tracts might be affected.

Pollution Rates by Monitoring Stations

Figure 10 and 11 represent the average values of total suspended particulates (TSP) for the years 1984-1985, and support subhypothesis H_b. The TSP measure was employed as an independent variable. The data for the TSP measurements were obtained from the Tulsa City-County Health Department (1984, 1985), and were recorded from the air pollution monitoring control stations situated in strategic points within the county.

Each station was plotted as a point for mapping purposes to produce a continuous gradient, isoline map (Figure 10). Census tract areal centers that fell within the path of a certain gradient were assigned that value of micrograms per cubic meter, the actual combined yearly average of TSP recorded at each station for years 1984 and 1985. A choropleth map (Figure 11) utilizing these values by census tract was then created to compare with the other choropleth maps.

The high values of TSP are clustered around the CBD. Other tracts containing the high rates of TSP are again in the Sand Springs area, tracts 63.01, 63.02, 64.01, and 88. In addition four tracts north of the CBD, 91.02, 91.03, 79, and 57 are receiving high measures of TSP. Tract 59 is noted for high rates.

When comparing maps, it must be kept in mind that air is not monitored in all sections of the city. Air is monitored where pollution sources are expected to be high. In one instance, tract 78, air is monitored as it enters the county from the south. TSP readings in the southern portion are the lowest for the county. There are no known pollution sources south of this tract.

Similarities are apparent when comparing Figure 6, the disease rate map, and Figure 11, the TSP rate. Those similarities are noted in the Sand Springs area, tracts 64.01, 63.01, and 63.02. A second high level of TSP extends east of the Sand Springs area to the CBD and then northeast. Tracts 91.02, 91.03, and 59 have the highest rate of disease

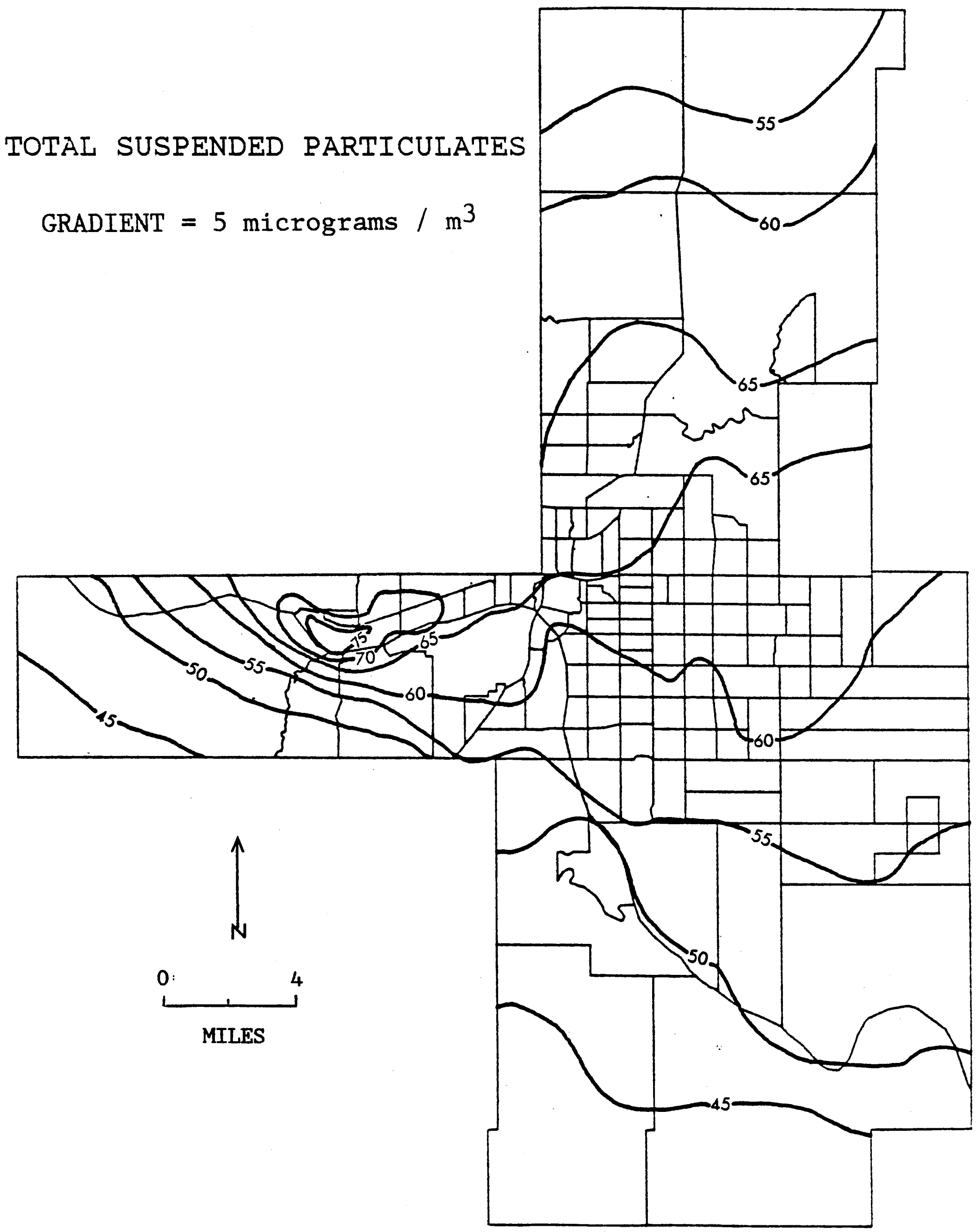


Figure 10. Iosline Map indicating gradient of pollution values for total suspended particulates in Tulsa County, Oklahoma 1984-1985.

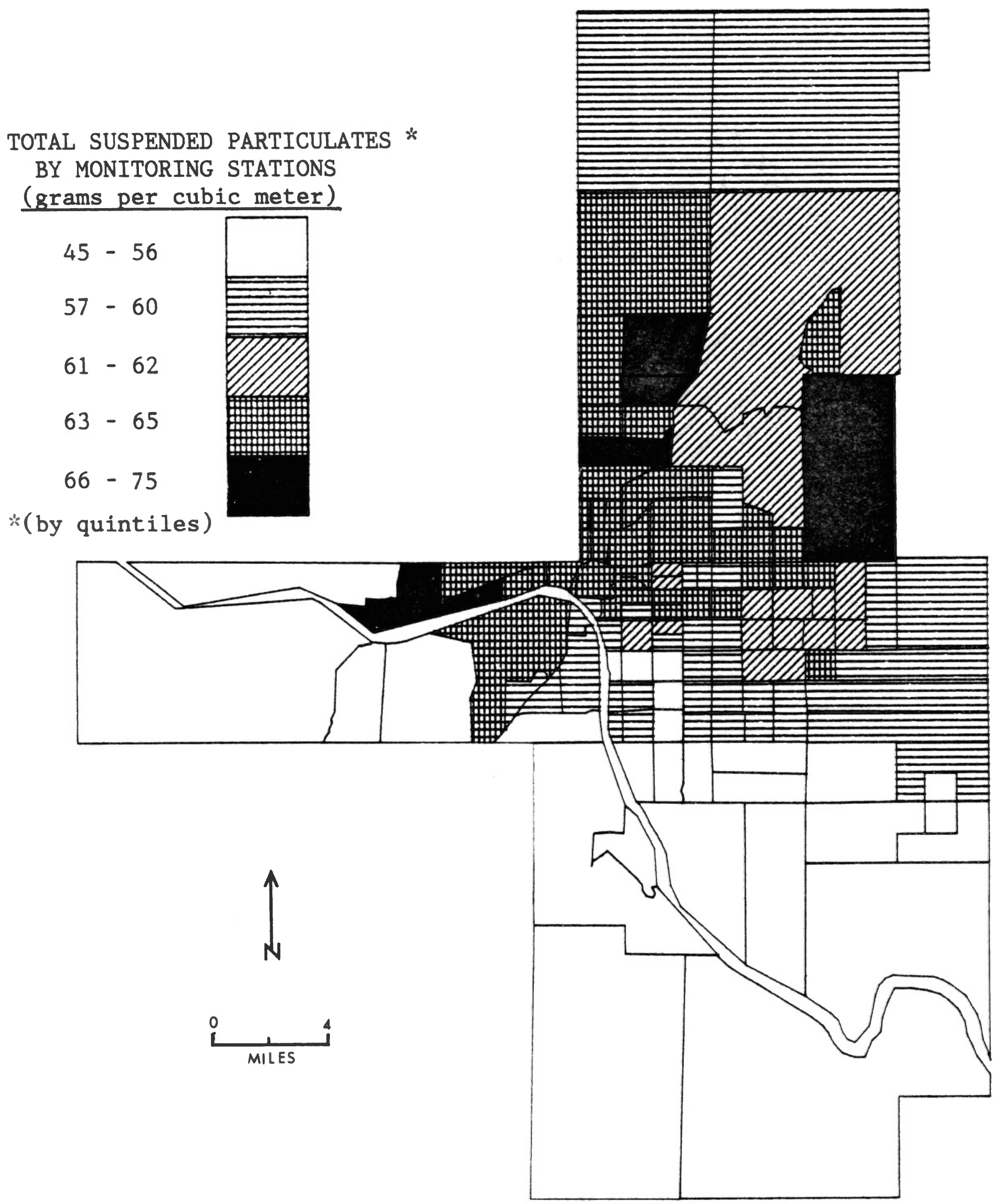


Figure 11. A choropleth map created by affixing a rate of TSP from a continuous surface map.

and TSP. On the other hand, there are those tracts that display totally opposite data, high rates of disease, low rates of TSP, 76.01, 85.01, and 76.05.

Correspondence Between Maps

The use of maps provides efficiency for the analysis of spatially-oriented data. These maps have displayed facts and spatial distributions, thereby aiding the analysis of the research. The maps displayed high risk communities and are implemented here to make final conclusions about the study. The results of inspecting the maps and analyzing their etiology, will be addressed in the final chapter of this thesis. The spatial patterns of this research give insight to the incidence of respiratory disease, however they cannot substitute for the greater understanding of the quantitative analysis that is necessary. Therefore, the integration of critical statistical analysis along with the mapped spatial patterns will better explain the occurrence of respiratory disease within Tulsa county.

Quantitative Analysis

The purpose of this section is to statistically test H_a and H_b. Several different tests were employed and the re-ults are recorded here by use of text and tables.

Patient Statistics

Frequency tests were performed to acquire a profile of the patient suffering from acute and chronic bronchitis.

The average patient in the hospital admission data was 69 years old, 86% were white, and 63% were male. Jackson (1986a) indicates that deaths eminating from chronic pulmonary obstruction on a nation-wide scale are predominately white male 86% of the time. Of the patients admitted to the hospitals of interest in this study for respiratory disease, 83% were over the age of 45. The literature review of this study clearly indicates that people over the age of 45 are affected more often than those of a lesser age. Therefore, the profile of the patient entering hospitals in Tulsa County are very similar to the profile of respiratory patients and deaths nationwide.

Smoking Data

Only 16% of the patients asked for rooms where smoking could be accommodated. It is postulated that any one of several situations might be involved here. The patient could have smoked in the past, and for various and obvious reasons had given up smoking. In addition, it is possible that not all patients would admit to having a smoking problem, especially if they had been told to stop smoking by their doctor. A recent report by the Center for Disease Control in Atlanta (1987) indicated that 26.5% of America's population are smokers. It is not known, however, what percent of this figure suffer from respiratory distress.

Lambert and Reid (1970) questioned 18,000 men and women about smoking and bronchitis symptoms. Controlling for smoking, it was found that the urban-rural gradient in bronchitis symptoms could not be explained by smoking differences alone. These researchers state, "Because of the many uncontrolled factors, one cannot have great confidence in the association between bronchitis symptoms in smokers and air pollution." This statement would therefore cast doubt on the outcome of research that claimed smoking was an inherent reason for respiratory distress when air pollution was also a factor.

In a similar study, Petrilli, Agnese, and Kanitz (1966) studied mortality and morbidity in Italy. They discovered that bronchitis was highly related with pollution levels. The subjects were females over the age of 65 who were nonsmokers and had never worked in industry. They had lived for a long period in the same area. Smoking was not an issue in Petrilli's subjects, and his conclusion that there is a strong relationship between bronchitis and pollution levels supports the present study's statistical results without the use of smoking data.

In 1964 Lammers, Schilling, and Walford compared English and Dutch cotton workers' chronic bronchitis and other respiratory symptoms. They concluded that the respiratory symptoms were greater in the English than in the Dutch workers. Smoking habits, occupational exposure (cotton dust), and air pollution were controlled. It was concluded that the presence of pollution offered the best explanation of the observed differences in the incidence of respiratory disease.

Smoking has been proven to be a contributor to lung disease. It is, however, very difficult to associate smoking with other contributors to the disease. It is an important variable, but was not in usable form to be a contributor in this research. However, other research has concluded that the exposure to ambient air pollution is the overriding factor as to whether humans will experience respiratory disease problems.

Analysis of Variance

Analysis of Variance (ANOVA) tests were employed utilizing the hospital rates as the dependent variable. Several combinations of class intervals were arranged to discover the interaction of the variables and to determine the best method of measurement H_a or H_b.

When the cumulative distance to the three closest sources of pollution in the upwind direction were modeled with the per capita disease rate, there was a significant difference between the means, (F=11.74; p=.0008). In modeling the the TSP and the disease rate there was also a high level of significance, (F=16.38; p=.0001). The outcome of the ANOVA tests indicate there is a significant relationship between the pollution measures and the disease rate. The null hypothesis can, in this case, be rejected and it can be concluded that distances to sources of pollution and the amount of pollution measured within a census tract have an effect on whether humans may suffer from respiratory disease.

Only a slight difference is noted between the F values of the two subhypotheses. Each measure produced high levels of significance and indicate that whether a person lives in a census tract near pollution sources or near high measures of TSP, he may experience substantial respiratory distress, enough that hospital admission is required.

Pearson Correlation Coefficients.

A Pearson correlation coefficient matrix was generated to test the strength of association between the variables, Table XI. There were 129 observations (census tracts) in this test.

In comparing the two distance measures, the measure that incorporates wind direction gives a higher correlation coefficient with the per capita disease rate than the measure that does not utilize a wind direction, (r=.38; p=.0001).

When TSP and the per capita rate of respiratory disease are plotted, a high correlation coefficient is obtained, (r=.42; p=.0001). The TSP measure explains somewhat more of the variance than the disance measure, but the outcomes of the two measures are very similar.

Surprisingly, the TSP and the distance measures do not correlate as high as might be expected (distance with wind direction r=.41, p=.0001; distance without wind direction r=.30; p=.0005).

The r value of the smoking data is relatively high when plotted against the UPI, (r=.30; p=.0005). This is not surprising as research reveals that a relative high percent of the urban poor smoke. Smoking and the TSP rates give high levels of significance (r=.29; p=.0006). Likewise, smoking and the distance utilizing wind direction indicates high levels of significance (r=.24; p=.0056). However, when the smoking data is correlated with the percapita and crude disease rates, their are no significant levels of association.

Stepwise Multiple Regression Models

A stepwise multiple regression model was employed to determine which of the independent variables would better explain or contribute to the incidence of respiratory disease. The computer output is given in Table XII.

Testing H_a, the distance from census tracts using wind direction, gives a better explanation of the variance (R^2=.14) than pollution sources regardless of wind direction (R2=.11). However, the use of TSP monitoring station reports, H_b, gives an R^2=.18. Adding the percent of patients who smoke and the UPI to the TSP data gives an R^2=.21. Utilizing the distance to pollution sources in a southerly direction, smoking, and the UPI gives an R^2=.19. A combination of TSP, the distance measure to sources of pollution, smoking information, and the UPI gave the best explanation of the variance with an R^2=.29. There are no other combinations of variables that would significantly improve the variance. The results indicate that only 29% of the variance is explained. Mayer (1986) states that when trying to explain relationships between ecological concepts

TABLE XI

PEARSON CORRELATION COEFFICIENTS
BETWEEN ALL VARIABLES
-A MATRIX-

	TSP	DIST. SOUTH	DIST.	SMOKING	Disease: Per Capita	Disease: Crude Rate	UPI
TSP	1.00000 0.0000	-0.41146 0.0001	-0.30156 0.0005	0.29887 0.0006	0.42666 0.0001	0.42724 0.0001	0.41648 0.0001
Dist. South	-0.41146 0.0001	1.00000 0.0000	0.75996 0.0001	-0.24269 0.0056	-0.38097 0.0001	-0.38016 0.0001	-0.22225 0.0114
Dist.	-0.30156 0.0005	0.75996 0.0001	1.00000 0.0000	-0.17840 0.0431	-0.34002 0.0001	-0.33807 0.0001	0.00659 0.9409
Smoking	0.29887 0.0006	-0.24269 0.0056	-0.17840 0.0431	1.00000 0.0000	-0.04371 0.6228	-0.03669 0.6797	0.30188 0.0005
Disease: Per Capita	0.42666 0.0001	-0.38097 0.0001	-0.34002 0.0001	-0.04371 0.6228	1.00000 0.0000	0.99909 0.0001	0.21658 0.0137
Disease: Crude Rate	0.42724 0.0001	-0.38016 0.0001	-0.33807 0.0001	-0.03669 0.6797	0.99909 0.0001	1.00000 0.0000	0.21732 0.0134
UPI	0.41648 0.0001	-0.22225 0.0114	0.00659 0.9409	0.30188 0.0005	0.21658 0.0137	0.21732 0.0134	1.00000 0.0000

Dist. = Pollution Measure regardless of wind direction
Dist. South = Pollution Measure using wind direction

TABLE XII

STEPWISE MULTIPLE REGRESSION TABLE

Number In Model	R^2	Variables in Model
1	0.00134634	SMOKE
1	0.04722809	INDEX1
1	0.11429466	DIST
1	0.14452376	DISTS
1	0.18253619	TSP
2	0.05874208	SMOKE INDEX1
2	0.12401398	DIST SMOKE
2	0.15024564	DISTS DIST
2	0.16219397	DISTS SMOKE
2	0.16249797	DIST INDEX1
2	0.16308418	DISTS INDEX1
2	0.18441248	TSP INDEX1
2	0.21220866	TSP SMOKE
2	0.23069578	TSP DIST
2	0.23281559	TSP DISTS
3	0.16772542	DISTS DIST SMOKE
3	0.17700450	DISTS DIST INDEX1
3	0.19301895	DIST SMOKE INDEX1
3	0.19362292	DISTS SMOKE INDEX1
3	0.21864624	TSP SMOKE INDEX1
3	0.23369190	TSP DISTS INDEX1
3	0.23673142	TSP DIST INDEX1
3	0.23941604	TSP DISTS DIST
3	0.26851244	TSP DIST SMOKE
3	0.27487052	TSP DISTS SMOKE
4	0.21056493	DISTS DIST SMOKE INDEX1
4	0.24250421	TSP DISTS DIST INDEX1
4	0.28000984	TSP DISTS SMOKE INDEX1
4	0.28128966	TSP DISTS DIST SMOKE
4	0.28392914	TSP DIST SMOKE INDEX1
5	0.29124205	TSP DISTS DIST SMOKE INDEX1

Index1 = UPI
Dist. = Pollution measure regardless of wind direction
Dists = Pollution using wind direction
Smoke = Whether or not the patient smokes

and chronic diseases, it is quite difficult to isolate the agents and/or causes that tend to be responsible for the disease. Meade (1983), investigated cardiovascular disease at the census tract level in Savannah. While Meade's study is still ongoing, she has made this statement concerning chronic disease studies,

> The causal explanations remain more elusive, and it is for this reason that the micro-scale behavioural analysis is particularly important.

The R^2 values are not large, but are statistically significant for large samples, especially for chronic disease studies. The difference between H_a and H_b is not great, however, the disease rate is somewhat better explained by the TSP measure.

Chi-Square

Disease Rate versus Urban Pathology. A Chi-square test was employed (Table XIII) to determine if the disease rates of patients admitted to hospitals and UPI were related. The UPI data were broken down into high and low status census tracts by looking above and below the median. Likewise, the disease rate (per capita index) of patients admitted to hospitals were broken down into high and low, above and below the median. The per capita rate was employed for the Chi-square testing because it is known that values above "1" indicate a higher than normal rate. Therefore, the grouping of the data is expected to provide more insight. There were 65 tracts that were classified as low status neighborhoods (high urban pathology), and 64 tracts were classified as high status neighborhoods (low urban pathology).

The Chi-square value produced by this test is 4.843. The liklihood of obtaining a score this high or better solely by chance alone is 0.028. There were more low status

TABLE XIII

CHI SQUARE TWO-WAY TABLE
DISEASE RATE VERSUS
URBAN PATHOLOGY

LOCATION QUOTIENT

URBAN PATHOLOGY	FREQUENCY / PERCENT / ROW PCT / COL PCT	DISEASE RATE Low 1	DISEASE RATE High 2	TOTAL
High Status	1	38 29.46 59.38 59.38	26 20.16 40.63 40.00	64 49.61
Low Status	2	26 20.16 40.00 40.63	39 30.23 60.00 60.00	65 50.39
	TOTAL	64 49.61	65 50.39	129 100.00

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	1	4.843	0.028

tracts (39) that had greater median admission rates than high status tracts (26). This indicates that low status tracts have higher disease rates more often than high status tracts.

Medicare or insurance type was not extracted from the patient records. If the poor were admitted to the hospital more often because Medicare paid for their hospitalization, then it might seem reasonable for the high UPI (low status neighborhoods) tracts to have higher disease rates. If this were the case, presumably all factors would be equal. Do the wealthy have higher rates of hospital admissions? One would expect that this is the case. However, the Chi-square results indicate that census tracts with a high UPI (low status neighborhood) have greater numbers of people being admitted to hospitals for respiratory disease.

Hospital Disease Rate Versus

Distance to Pollution Source. A Chi-square Test was employed to determine if there was a relationship between the number of tracts having a high percentage of people being admitted to hospitals and the closeness of these tracts to sources of pollution (Table XIV). Both variables, per capita disease rate and distance measure, were separated into two classes by observations above and below the median.

The Chi-square value produced by this test is 14.04, and the liklihood of producing this large a score or larger solely by chance is less than 0.001. Of the 64 tracts that were close to sources of pollution. 67% had high disease rates. In addition, of the 65 tracts that were further away from major sources of pollution, 66% indicated low disease rates. It can therefore be concluded that living close to sources of major pollutors is significantly related to high disease rates, supporting subhypothesis H_a.

TABLE XIV

CHI-SQUARE TWO-WAY TABLE
DISEASE RATE VERSUS
DISTANCE FROM TRACT
TO POLLUTION SOURCE

LOCATION QUOTIENT

DISTANCES FROM SOURCES OF POLLUTION	FREQUENCY / PERCENT / ROW PCT / COL PCT	DISEASE RATE Low 1	DISEASE RATE High 2	TOTAL
Close	1	21 16.28 32.81 32.81	43 33.33 67.19 66.15	64 49.61
Far	2	43 33.33 66.15 67.19	22 17.05 33.85 33.85	65 50.39
	TOTAL	64 49.61	65 50.39	129 100.00

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	1	14.340	0.000

Disease Rate versus Monitored TSP. A Chi-square Test was employed to determine if there is a relationship between the number of tracts having a high number of people being admitted to hospitals and the rate of TSP measured by a continuous gradient as recorded at monitoring stations (Table XV). The data were divided above and below the median.

The Chi-square value produced by this test is 15.70. The liklihood of obtaining a score this large or larger solely by chance is less than 0.001. The results indicate that of the 62 tracts having a low TSP rate, 67% were associated with low hospital admission rates. Of the 67 tracts with high TSP readings, 67% indicated high admission rates. The outcome of this test indicates that in tracts where disease rates are high, 69% of the tracts have high readings of TSP. It has therefore been confirmed that monitored rates of TSP are statistically related to the per capita rates of respiratory disease, supporting subhypothesis H_b.

Analysis of Model Residuals

Residuals of predicted values were employed to determine if boundary or spatial problems existed between the dependent and independent variables. A regression program used per capita respiratory disease hospital admission rates as the dependent variable against the distance to pollution sources (H_a) as the independent variable. A second model used the per capita respiratory disease hospital admission

TABLE XV

CHI-SQUARE TWO WAY TABLE
DISEASE RATES VERSUS
MONITORING STATIONS

LOCATION QUOTIENT

TOTAL SUSPENDED PARTICULATES

FREQUENCY PERCENT ROW PCT COL PCT	DISEASE RATE Low 1	High 2	TOTAL
Low Rates 1	42 32.56 67.74 65.63	20 15.50 32.26 30.77	62 48.06
High Rates 2	22 17.05 32.84 34.38	45 34.88 67.16 69.23	67 51.94
TOTAL	64 49.61	65 50.39	129 100.00

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	1	15.695	0.000

rates as the dependent variable against the independent variable, TSP, utilizing (H_b). The models produced a list of residuals by census tract. Sketch maps of the residuals were drawn using quartiles for intervals. The maps indicated that there were no spatial patterns resulting from oversized tracts. The under-and over-predicted values appeared sporadically in both large and small-sized tracts throughout the county. The largest tracts were over-predicted, but also are located away from the city center and the major sources of pollution. Tracts with low residual values were located near the center of the county and near the pollution sources. The results of this analysis suggest that neither the size nor the location of the individual census tracts consistently biased the results.

Conclusion

The mapped phenomena provided a check for the statistical testing of the actual data. The testing of the dependent variables against the independent variables by using ANOVA, the stepwise multiple regression, and the Pearson correlation coefficient were statistically significant in most cases. The Chi-square tests were concluded to be the most relevant method of testing the data, producing high Chi-square values and low levels of probabilities. The testing of the two hypotheses supplied a check against the pollution data and were closely correlated throughout the testing.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Overview

The purpose of this chapter is to draw conclusions from the results presented in Data Analysis to answer the question posed, is there a spatial relationship between ambient air pollution and place of residence of respiratory disease patients in Tulsa County, Oklahoma. Conclusions will be made concerning the major hypothesis. In addition, the outcome of testing the two subhypotheses will be presented. The conclusions will be followed by recommendations for future research.

Findings

"Significance of a correlation coefficient is a function of the magnitude of the correlation and the sample size" (Cody, 1987). When a large number of data observations are used, a correlation coefficient of .16 would be significant at the .05 level. Likewise, when around 10 observations are used, a correlation coefficient of .63 would be considered significant. The current study used 129 census tracts as observations.

With the foregoing in mind, associations and conclusions drawn from the analysis of data were based solely on the outcome of the information that was provided by various reliable sources, namely the three participating hospitals and the Tulsa City-County Health Department. Those conclusions will be based on the strength of the associations provided by the SAS programming and the visual observation of the mapped data.

Three goals and objectives were defined in the introduction of this research. The first objective concluded that this research would establish confidence that respiratory disease is greatly affected by air pollution. The second defined how the first would be accomplished, namely through the analysis of respiratory disease rates along with pollution rates and selected socioeconomic census variables by means of statistical analysis. The literature review gave credence to the fact that research has established a relationship between air pollution and respiratory disease and that more reliable research is needed. The foregoing chapter has established that there are relationships existing within Tulsa County where disease rates may be affected by the air quality. The third objective of this study is that conclusions will be made based on the outcome of the analysis between the variables and decide the better method of measuring the pollution rates, either H_a or H_b. The following statements will address this third objective.

There are similarities as well as differences in comparing the choropleth maps presented in the analysis. In most cases, high rates of disease exist where intense areas of pollution are present. When the rate of disease map is compared with either of the two maps portraying pollution rates, it is evident that the high rates of disease follow the Arkansas River channel for a distance and are less in areas where there are no major pollution sources. It is also evident that disease rates in and around the major pollutors tend to disperse in a north-easterly direction. The dispersion of the disease rates could be said to go down wind from most sources of pollution. There are cases, however, where this does not happen. It should be kept in mind that not all sources of pollution were utilized in this study.

The urban pathology index (UPI) map defines socio-economic problem areas. These tracts, with one exception indicate the highest rates of UPI exist where pollution sources are nearby or in the downwind direction of pollution sources.

When the UPI and the two pollution-measure maps are compared, there are some similarities, as well as differences. For example, the rural areas will often have high levels of UPI, but the disease rates will be low. An explanation could be that the UPI is measuring low income, percent black, and substandard housing. In rural areas, low income and substandard housing are factors contributing to a high UPI. Pollution, on the other hand, is usually not high because the sources of emission are further away from the rural areas. Disease rates were always lower in the rural areas of the county. However, the Chi-Square test results indicated that more tracts with high UPI are treated for disease than tracts with low UPI. The maps then contribute to the study by indicating that the tracts that do indeed have a high correlation with disease rates are those tracts centered within the county away from the rural areas and closer to the sources of pollution.

Results of analysis of variance between the dependent variable and the pollution measures were very significant: (TSP = F=14.77; df=3, 125; p=.0002) (Distance Measure = F=11.74; df=3, 125; p=.0008). There was no clear distinction here about the preference of use for subhypotheses H_a or H_b.

A stepwise multiple regression model was employed to generate an R^2 value for an explanation of the variance. Utilizing all independent variables, smoking, total suspended particulates (TSP), UPI, distance to pollution sources, an explanation of the variance was given (R^2=.29). This is a significant finding for large samples. Of the two subhypotheses, TSP produced a slightly higher R^2 value (R^2=.18) over the distance measure (R^2=.14). Comparing the two subhypotheses, the difference was defined but not greatly.

Significant levels of associations were found when a Pearson correlation coefficient matrix was generated. The TSP measure, when correlated with the disease rate produced a highly significant correlation coefficient (r=42; p=.0001). The distance measure, likewise, produced correlations that insured that real relationships existed between the pollution measure and the disease rate (r=.38; p=.0001). A slightly higher correlation coefficient was obtained by using the TSP measure, however the difference was not great between the two subhypotheses.

One component of the study included the testing of an urban pathology index. The UPI indicated significant levels of association to the pollution measures through the Pearson correlation coefficient matrix. TSP and the UPI produced a high level of significance, (r=.42; p=.0001). The distance measure that incorporated wind direction was significantly related to the UPI, (r=.22; p=.0114). Smoking and UPI correlations were significantly related, (r=.30; p=.0005).

Chi-square analysis gave overall the best explanation of the data. When the census tracts were divided into either high or low UPI, it was noted that people in poorer tracts were being treated in hospitals 60% more often than people living in higher status tracts. It is evident by observing Figures 7, 8, 9, and 10 that the poor live closer to the pollution sources. It is postulated here that although many factors are involved in the incidence of respiratory disease, a significant contributor to the disease rate is a person's place of residence and its proximity to major sources of pollution.

The results of the Chi-square testing gave a strong indication that people living in census tracts near sources of pollution and where TSP rates are high are being treated in the hospital a greater percent of the time. When the two subhypothesis were tested. the Chi-square scores were between 14.34 and 15.70. The liklihood of these scores resulting by chance was 0.000. The very high Chi-square value and the low probability indicates that high measures of TSP and distance from census tract of residence do indeed make a difference as to whether people will be treated in hospitals for respiratory distress. The differences between the two subhypotheses measures again were not appreciable.

The results of the mapped data and statistical testing are congruent with studies presented in the literature section of the present study. The several tests that were employed supplied a check for the research and were supported in each instance.

When comparing the outcome of the analysis as to which method of measuring pollution was the most conclusive, the stations monitoring TSP gave higher levels of significance in all of the statistical tests. The differences between the outcome of the measurements were defined. but not greatly different. If the differences were great, however, it might suggest that there were inherent errors within the data. Therefore. the two different analysis provided a check on each method of measurement and gives support to the conclusions presented above.

The results of this study suggest that a choice of place of residence may well be a contributing factor as to whether a person will suffer acute and/or chronic bronchitis. The mapped data indicate that people living downwind suffer more often than upwind from pollution sources. The likihood of being a white male, 69 years of age, and living in a low status neighborhood contribute to the incidence of respiratory disease patients. The smoking and occupation could not be reliably analyzed because of insufficient data.

It is concluded that there was a spatial relationship between ambient air quality and respiratory disease in Tulsa County, Oklahoma in the years 1984-1985. The main hypothesis of this thesis was, therefore, accepted and nearly equally supported by either of the following two subhypotheses: H_a, the rate of patients with respiratory illness admitted to hospitals decreases with distance from major pollution sources; Hb, the rate of patients with respiratory illness admitted to hospitals are relatiavely high when monitered air pollution levels are relatively high in their residential area. H_b did, however, indicate higher levels of significance in every statistical test that was employed. The difference was not great, but H_b might be considered the better method of measurement. It would seem reasonable, therefore, to revise the subhypothesis to read as follows:

> The rate of patients with respiratory illness admitted to hospitals are high when monitored air pollution levels are high and/or when major pollution sources are nearby.

Factors Hindering the Study

Disease Causes

All possible causes for the incidence of respiratory disease or any disease is not wholly dependent on any one factor. In most cases, many different phenomena may play a significant role. Because 90% of an individual's time is spent indoors and much of that in his residence, this thesis postulates that a person's residence and its proximity to sources of pollution is a large contributing factor to whether that person will experience respiratory distress.

Three hospitals contributed patient records for the present research. The inclusion of the fourth hospital, Oklahoma Osteopathic, would have increased the available bed capacity from 71% to 88%. In so doing, a greater geographic coverage of the county could have been obtained. However, the unavailability of computerized documents precluded this effort.

Patient records from hospitals are a good source for supplying information about a person; his/her address, age, sex, race, disease type, occupation, and smoking information. However, these records do not portray a complete profile of the patient's background and lifestyle. In addition, the given information is not always reliable. For example, the patient's address is not always representative of long-term residence. Likewise, information on smoking habits and occupation is not always reliable.

<u>Census Data</u>

The UPI that was employed in the present study was calculated from the 1980 Census; likewise, the population data. The air pollution data and the patient data were taken from 1984 and 1985 records. It is obvious that discrepencies were inherent in the data because of this time span. However, reliable population projections were not available (Renner, 1987).

Measuring Pollution

The lack of sufficient monitoring stations within the county leaves some questions about control points and the interpolation of the TSP data. There are also lacks of control when assigning pollution rates to tracts by using a distance measure. For example, wind speed and direction change constantly and there are no specifics involved as to which direction and how fast pollution plumes will travel. In addition, there are many sources of pollution that are uncontrolled and/or unmonitored. The present study employed data from 31 major pollution sources within the county. However, there are 116 industrial pollution sources in the county.

Pollution sources outside of the county boundary may have been responsible for disease rates that were elevated within the county. Because only Tulsa County pollution sources were utilized in the present study, it is possible to assume that the outcome of some of the statistical tests were affected.

Recommendations

The results of the present study serve to emphasize the need for cleaner air and closer monitoring of all areas within a metropolitan center. Information concerning ambient air should be made readily available to the public who seek to make their homes in any given area.

Future studies would be greatly helped if patient records contained greater information on the occupation of the patient. Some hospitals are now attempting to do this, i.e., Texas and New Hampshire (Trost, 1985). Occupation data would then be benficial. The hospital data used in this study would only supply the company name and not the job type, i.e., American Airlines, rather than Diesel Mechanic.

The Government Base File (GBF) software was very difficult to fit to the hospital data, and because the hospital data were not standardized the GBF software did not always assign the tract. The 1990 Census will use a new program for assigning small geographic areas. This new program is referred to as the TIGER program and is a more efficient geographic base file.

More hospitals now hold computerized data from their admission records, and additional patient information would certainly benefit future studies. Outpatient clinics in the poverty area would no doubt supply an interesting component to the study.

Continued studies to improve the quality of life are greatly needed. Pollution and disease will continue as populations grow and affluent societies prevail. Monetary support must be made available to monitor and provide surveilance to ongoing studies.

Medical geography is much needed and its integration with cognate fields such as city-county health departments, hospitals, and state and federal health agencies will serve to improve the quality of life in a given community. Moveover, preventative planning is a key to decreasing disease. If source information can be obtained and cause can be assigned, then prevention can be implemented. Societies could then make choices based on information supplied by health agencies. Those agencies should work to procure knowledge and implement a plan to protect those societies. Medical geography has the potential to provide the public with source data that turns unseen hazards such as ambient air pollution into known and spatially defined facts.

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VITA 2

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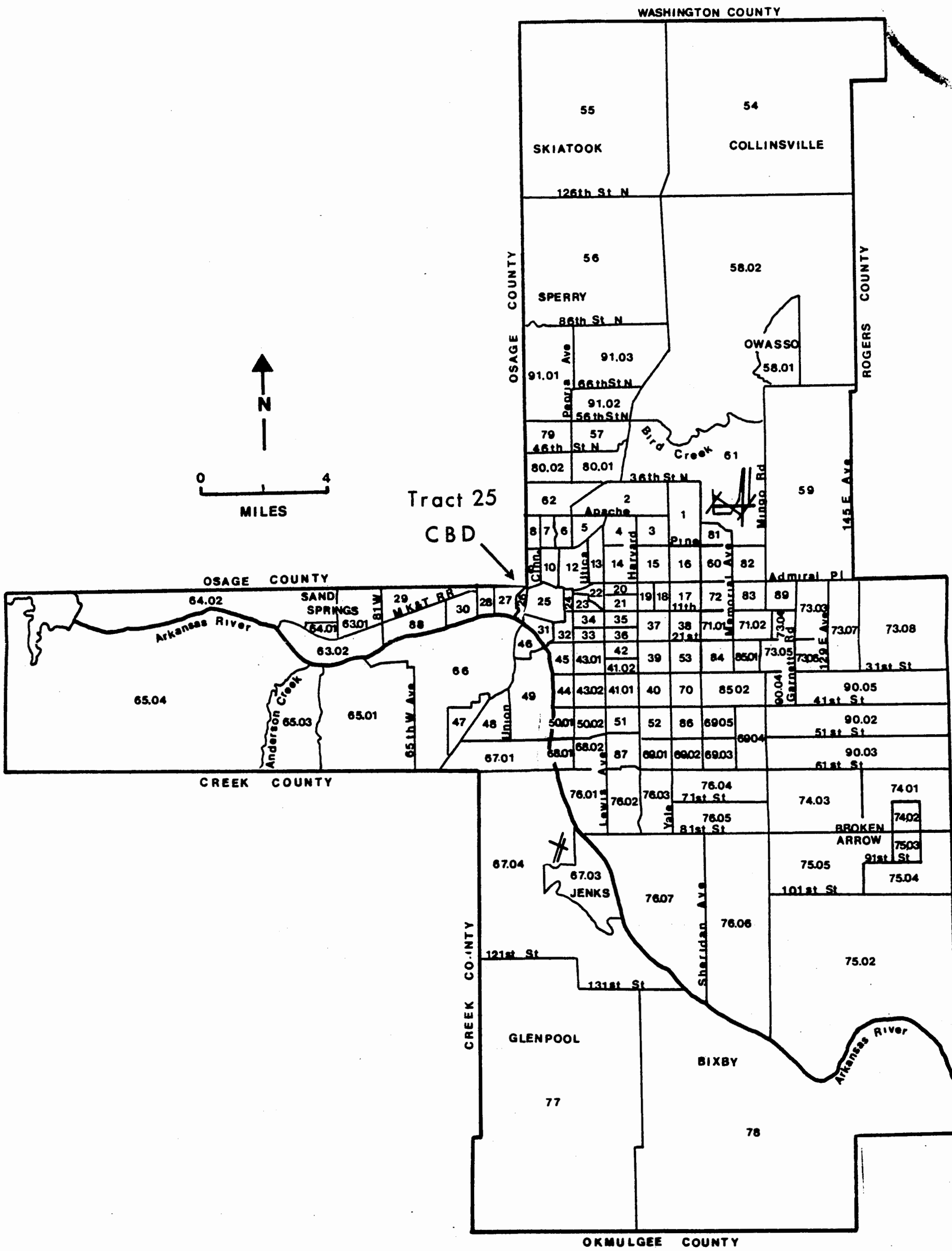

Figure 12. Census tract map of Tulsa County