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RESEARCH ARTICLE

An Examination of Stroke and Air Pollution Trends in Taiwan, 1990 to 2022

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ABSTRACT: Air pollution has been found to correlate with rising stroke levels in Taiwan's population, but a comprehensive analysis of trends throughout the past three decades has not yet been done. While research is still ongoing into the biological mechanisms through which airborne pollutants affect the vasculature, pollution is thought to increase the risk of stroke by hardening arteries in the brain and increasing the risk of clots. Taiwan's concentration of industrial sectors and its mountainous topography– which traps airborne pollution– make the issue especially serious. In Taiwan, stroke is the most common cause of disability and the third most common cause of death. This topic has been examined before but not evaluated in a longer timeframe. To investigate this, I conducted a literature review from 1995 to 2022 and analyzed current epidemiological data to analyze trends and identify solutions. This research not only depicts Taiwanese residents' situation but that of the global community as a whole. Jet streams moving across the earth are distributing pollution from various places while simultaneously, stroke is growing as a global health risk, making this a universally relevant issue.

KEYWORDS: Translational Medical Sciences; Disease Prevention; Stroke; Air pollution; Taiwan; Cardiovascular disease; Cerebrovascular disease; East Asia.

Introduction

Over the last three decades, evidence has emerged linking air pollution and cardiovascular mortality and morbidity, and pollution is responsible for approximately 9 million deaths per year, about 1 in 6 deaths globally.[1] The island nation of Taiwan has both high levels of air pollution and a population more susceptible to stroke, making it an interesting avenue to examine this issue. In 2020, 16% of Taiwan's population was 65 years old and above, a share which is projected to grow to 40% by 2060.[2] Health conditions such as cardiovascular diseases, stroke, and diabetes are increasingly common due to the island's aging population. In addition, stroke is the leading cause of complex disability, often leaving survivors and their families with severe financial issues due to their inability to work. Increasing air pollution has influenced stroke morbidity and mortality worldwide, including in Taiwan. One form of pollution, particular matter or $PM_{2.5}$ (tiny particles or droplets in the air that are two and one-half microns or less in width), is capable of entering the lungs and the bloodstream, causing cardiovascular, cerebrovascular (stroke), and respiratory issues.[3] Although the biological links between stroke and air pollution have been thoroughly examined, a holistic review of all research on this topic in Taiwan has not been done in the last three decades. Therefore, this review set out to evaluate the extent to which different forms of air pollution in Taiwan have affected the susceptibility to stroke of its population throughout the years.

Introduction to air pollution

What is Air Pollution?:

Air pollution is a general term that includes a mixture of numerous components from various sources. Currently, airborne particulate matter (PM) and gaseous pollutants such as ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen oxides, including nitrogen dioxide (NO_2) and nitrogen oxide (NO), are considered to pose a risk to human health.[4] $PM_{2.5}$ is generally accepted as the most harmful to human health due to the range of health effects it is associated with, as well as its ubiquity in the environment.[5]

Human-produced air pollution typically comes from sources such as vehicle emissions, fuel oils, and natural gas used to heat homes, byproducts of commercial manufacturing, and power generation– specifically coal-powered power plants. Natural air pollution is another contributor; smoke released by wildfires, ash and gasses from volcanic eruptions, and gasses such as methane are all produced naturally, though human activities can exacerbate negative impacts.[6]

Increasing Global Concerns:

While global rates of air pollution are improving, 99% of the global population still breathes air that exceeds the World Health Organization's air quality limits.[7] Over 6,000 cities in 117 countries are now monitoring air quality, but their residents are still being exposed to harmful levels of fine particulate matter and nitrogen dioxide. Low and middle-income countries are exposed to the highest pollution levels, with less than 1% of cities in compliance with WHO recommendations.[7]

Air pollution is especially harmful to already vulnerable populations. In 2021, an estimated 40,000 deaths under the age of five were directly linked to $PM_{2.5}$ air pollution.[8] Populations with different biological coping capacities– the elderly, fetuses and children, and people with pre-existing diseases are far more impacted by air pollution than average.[9] In the United States, a meta-analysis found a strong negative association be-

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tween socioeconomic status and air pollution exposure and a similar trend in other areas, including New Zealand, Asia, and Africa.[10] Recent research also shows that exposure to $PM_{2.5}$ increases both the risk of contracting COVID-19 and suffering more severe symptoms when infected, including death.[11]

Taiwan's Vulnerability to Pollution:

Air pollution in Taiwan was the highest among the Four Asian Tigers– Hong Kong, Singapore, South Korea, and Taiwan–[12] and even higher than some cities in China and Southeast Asia. Additionally, the annual PM_{10} (particulate matter with a diameter of 10 micrometers or smaller) average in Taipei ranked 1,089 out of 1,600 cities worldwide.[13] The yearly average of $PM_{2.5}$ exposure in Taiwan has been at 20-30 [μg/m3]-- four to six times the current WHO guidelines– for the past three decades.[14, 55]

Taiwan's mountainous topography and robust industrial sector contribute to its high air pollution concentration. Taiwan's capital city is situated within the Taipei Basin– a "bowl" surrounded by mountains.[15] This causes the formation of temperature inversions (when air temperature increases by height, trapping cooler air below), which can trap smog and other pollutants.[16] Polluting industries are concentrated in specific locales; industrial centers are located along its northern and western coasts, surrounded by water and high mountains. Domestic sources of pollution, such as incineration of organic matter, combustion of fossil fuels, and automobile traffic within cities, also contribute to the pollution issue.[17]

How Air Pollution Spreads:

Air pollution can spread worldwide through wind patterns and jet streams, meaning that pollution originating in Asia can still affect places on the other side of the world. East Asian pollutants such as carbon monoxide (CO), nitrogen oxides (NO), particulate matter (PM), and sulfur oxides (SO_X)[18] are emitted from combustion and industrial sources and are carried toward the equator by cold winds.[19] These pollutants cross the North Pacific Ocean in the mid to upper troposphere (the lowest region of the atmosphere) and have even been documented to descend to the surface in North America.[20] Studies have recorded frequent exportation of Asian dust, sulfate aerosol, and mercury to western North America.[20] In 2006, export-related air pollution originating in China accounted for 12 to 24% of sulfate concentrations in the Western United States.[56] Precipitation and transportation of food can also distribute pollution.[21] Hemispheric transport of air pollution is especially difficult to control because it would likely require international regulation.[56]

Many cities in western Taiwan are affected by both local and transboundary pollutants; Taiwan's geographic location– close to the southeast of China– often receives transboundary pollution from East Asia and Indochina.[22] Despite rapid progress in combating the issue, China remains the tenth most polluted country globally, with particulate pollution almost four times the WHO guideline.[23] Northeastern monsoons in the winter can transport airborne particulate matter ($PM_{2.5}$) from northern China, Korea, and Japan towards downwind regions such as Taiwan and the Philippines.[24] This type of long-range transport causes the deterioration of regional and ambient air quality in those areas.[25]

How Air Pollution Affects the Body (Biologically):

In 2019, the Global Burden of Disease Study found that air pollution– which includes ambient particulate matter pollution (with a diameter of <2.5 μm; $PM_{2.5}$)– contributed to 213 million DALYs (disability-adjusted life years) and 6.67 million deaths.[26] In Latin America, where large populations were exposed to relatively high levels of air pollution, a meta-analysis found that an increased risk of mortality was strongly associated with increased ambient concentrations of PM_{10} and O_3 gasses– previous corroborating observations in other parts of the world. The same study also found that people with lower socioeconomic status, infants, and young children were more susceptible to both PM_{10} and O_3.[27] Primary and secondary pollutants can also exacerbate the effects of climate change, affecting public health through more extreme temperatures and lessening crop yields.[28]

Various diseases and health conditions are associated with air pollution, most commonly of the respiratory and circular systems. For example, in response to higher ambient PM concentrations, hospital admissions in the United Kingdom for several cardiovascular and pulmonary diseases acutely increased.[29] It was also found that prenatal or perinatal exposure to air pollutants could lead to the late onset of respiratory diseases in children and adults.[30] Particulate matter can enter the bronchopulmonary tract, passing multiple protective mechanisms depending on the size and chemical nature of the pollutants.[30] For example, $PM_{2.5}$ can invade more deeply into the lungs due to its smaller size.

Additionally, air pollution also impairs human health through both development and chronic disease. Exposure to vehicular pollutants was associated with quantifiable impairment of brain development in the young and the exacerbation of cognitive decline in the elderly.[31] PM_{10} air pollution may also be associated with higher average blood sugar levels in newly diagnosed type 2 diabetes patients.[32] Additional correlations were also found with preterm birth, reproductive health, rheumatic diseases, and neurodegenerative diseases.[33-36]

Air pollution can enter the body through the skin or the lungs when we breathe, where it can then enter the bloodstream.[37,38] Because of its ubiquity in our environments and how easily it enters the body, it can be almost impossible to avoid the health effects of pollution. Air pollution can affect ecosystems in various ways– causing acid rain, contaminating water sources and soil, and even killing plants or animals.[39]

Overview of Stroke:

A stroke, also known as a brain attack, occurs when the blood supply to part of the brain is blocked or a blood vessel within the brain bursts. In both cases, parts of the brain become damaged and die, which can cause lasting brain damage, long-term disability, or even death. The brain controls the body's movements and functions, stores memories, and is the source of all thoughts, emotions, and language. To work correctly, the brain needs oxygen-rich blood, which the arteries supply. However, brain cells start to die within minutes if something blocks the blood flow, causing a stroke.[40]

In 2019, stroke was the second leading cause of death globally, and prevalence increases as the world population ages.[41] Additionally, more and more young people are being affected; the burden of stroke in people under 65 years increased over the past few decades, with the incidence rising by 25% amongst adults between 20 to 64 years.[42]

Quick treatment is critical for recovery, but in a survey done by the CDC, only 38% of respondents in the United States were aware of all significant symptoms and knew to call 911.[43] Due to its ability to cause immense damage to a person's health in the span of minutes, its growing prevalence, and the lack of life-saving awareness surrounding its treatment, stroke is an extremely critical public health issue.

Stroke in Taiwan:

Stroke is the third leading cause of death and the most common cause of disability in Taiwan.[44] Other factors such as age, gender, hypertension, diabetes, obesity, atrial fibrillation, and smoking contribute significantly to stroke morbidity. The average years of potential life lost before age 70 for stroke is 13.8 years. Stroke also significantly burdens the Taiwanese national healthcare system, costing an estimated 475 million US dollars.[44]

In contrast to Western countries[45], the incidence of stroke is rising in Taiwan, according to a study presented at the ASEAN Federation of Cardiology Congress in 2018. After adjusting for the aging population, the incidence of ischemic stroke increased from 110 to 122 per 100,000 person-years, and intracerebral hemorrhage rose from 30 to 38 per 100,000 person-years.[46] Cardiovascular disease remains a significant cause of death in Asian populations, and previous reports have shown that stroke is more common in Asian than in Western populations.[46] In 2002, 60% of the world's total stroke mortality occurred in East Asia.[47] Asian populations tend to be more susceptible to stroke due to aging populations and underlying genetic predispositions.[48]

Summary of Literature on Air Pollution and Stroke in Taiwan :

The link between pollution rates and cerebrovascular disease burden in Taiwan has been examined in numerous previous studies. The general consensus is that increased rates of hospital admissions for a variety of cardiovascular events are associated with short term[57-61] exposure to pollutants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and $PM_{2.5}$ and PM_{10} and that certain patients (such as those with advanced age and hypertension) are more susceptible to air pollution's impacts on hospitalization.[62]

Residents of Kaohsiung– a city on the southwest coast of Taiwan and the center of the island's heavy industry– showed elevated rates of cerebrovascular disease.[60] Sources of pollution include frequent Asian dust storm (ADS) events (when dust originating in Mongolia and China is windbloswn to Taiwan)[63,64], and traffic-related pollution.[65,66]

Methods

A comprehensive search of peer-reviewed journals, articles, and reports was completed using a set of key terms, including stroke and air pollution, stroke and Taiwan, air pollution and cardiovascular disease, pollution and cerebrovascular disorder, air pollution and health, ischemic stroke, and air pollution in Taiwan. The main database used was the United States National Library of Medicine's PubMed database. I additionally reviewed the references section of each article to find additional information. This search covered 29 peer-reviewed articles published between 1995 and 2022, cited throughout.

Using Excel functions, I calculated the R2 values and correlation coefficients from data on the mortality rate of cerebrovascular diseases and the recorded levels of different air pollutants from 2010 to 2015 in Taiwan. The data for mortality rate was obtained through the Statista database and was cross-referenced for accuracy with studies of cerebrovascular mortality rate in Taiwan from the literature examined in this review.[49,53] The pollutant data was obtained from a cohort study conducted in Taiwan, which used data on air pollutants from air quality monitoring stations across Taiwan and evaluated the risk of stroke using stroke data from Taiwan's universal health insurance program.[49]

Results and Discussion

Data Analysis:

I compiled stroke and air pollution data in Taiwan to investigate the trends and plotted them to identify potential correlations. Figure 1 shows the annual cerebrovascular disease mortality rate and year from 2010 to 2020, demonstrating the overall trend for stroke prevalence in the past few decades. Figure 2 shows the annual NO_2, SO_2, $PM_{2.5}$, NO_X, and O_3 pollution rates in Taiwan versus the year to illustrate pollution trends throughout the study period (annual average pollution levels are summarized across periods with varying pollution levels). Both stroke and pollution rates have been on a downward trend in Taiwan. Then, individual pollutants were plotted with annual cerebrovascular mortality rates to determine whether the two factors were correlated (Figures 3-7). $PM_{2.5}$ and O_3 pollution seemed to be the most correlated with stroke prevalence, with correlation coefficients of 0.72 and 0.892, respectively. The other forms of pollutants had lower correlation coefficients ((Figures 3-7; Table 1).

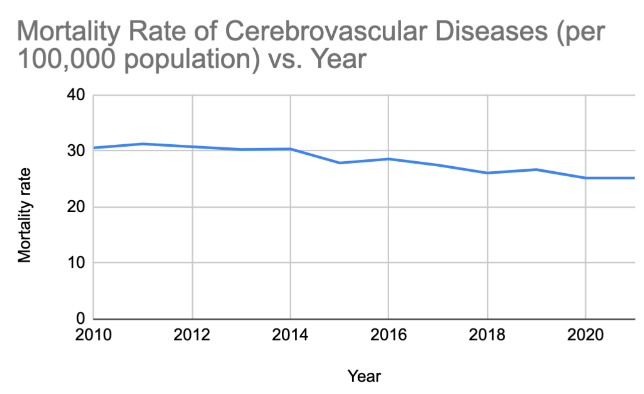

Figure 1: The annual mortality rate of Cererovascular diseases in the years 2010 to 2021.

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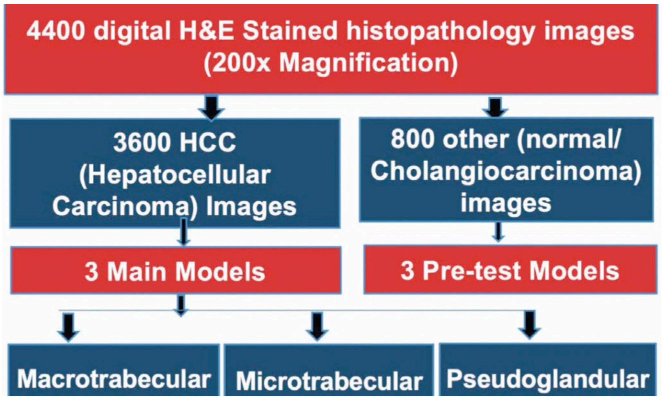

Figure 2: Years 2010 to 2015 and annual rates of pollutants NO_2, SO_2, $PM_{2.5}$, NO_X, and O_3.[53, 49].

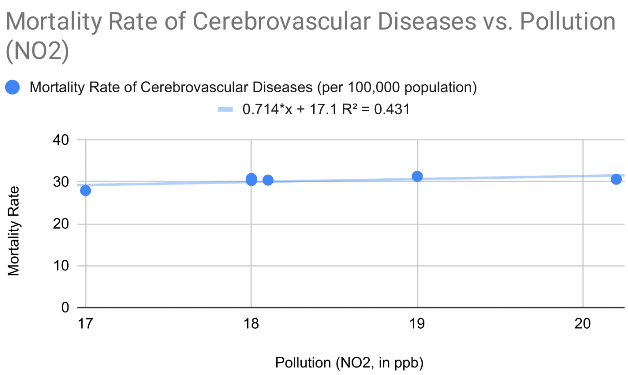

Figure 3: The annual rates of cerebrovascular disease mortality and pollution (NO_2), 2010 to 2015.[53]

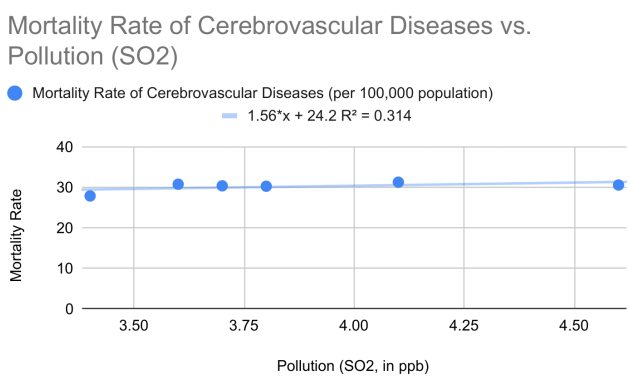

Figure 4: The annual rates of cerebrovascular disease mortality and pollution (SO_2), 2010 to 2015.[49, 53]

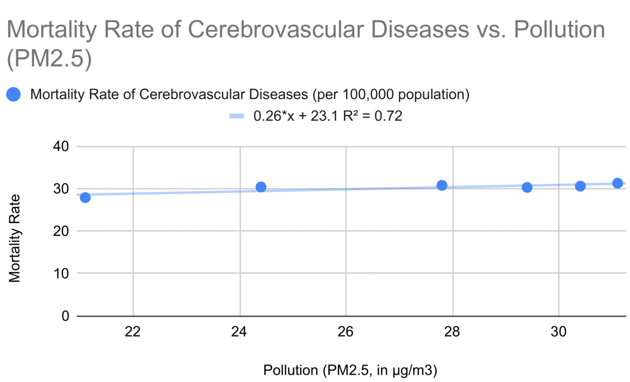

Figure 5: The annual rates of cerebrovascular disease mortality and pollution ($PM_{2.5}$), 2010 to 2015.[49, 53]

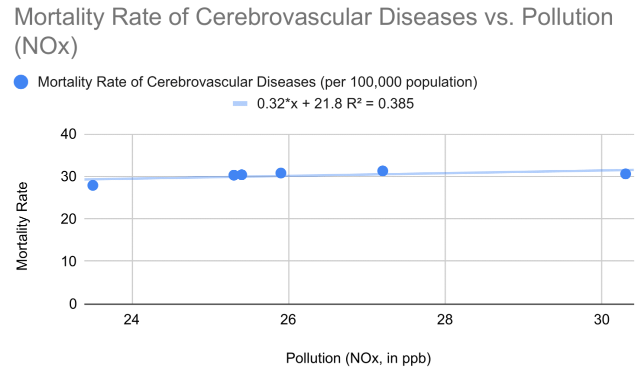

Figure 6: The annual rates of cerebrovascular disease mortality and pollution (NOx), 2010 to 2015.[49, 53]

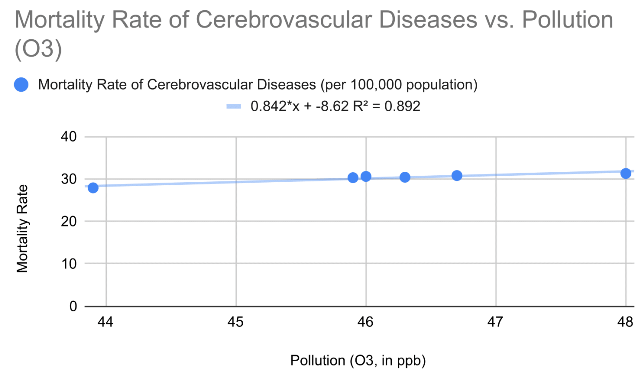

Figure 7: The annual rates of cerebrovascular disease mortality and pollution (O_3), 2010 to 2015.[49, 53]

Table 1: R^2 values and correlation coefficients for each pollutant with the mortality rate of cerebrovascular diseases, from highest to lowest correlation.

Pollutant	R^2	Correlation coefficient
NO_2 (ppb)	0.431	0.66
SO_2 (ppb)	0.314	0.56
$PM_{2.5}$ (μg/m3)	0.72	0.85
NO_x (ppb)	0.385	0.62
O_3 (ppb)	0.892	0.94

Conclusion

The variation in the correlation between pollutant types and the stroke mortality rate has interesting implications. $PM_{2.5}$ and O_3 pollution seemed to be the most correlated with stroke prevalence, with correlation coefficients of 0.72 and 0.892, respectively. O_3 had the highest concentrations overall, which may be the reason behind its higher correlation coefficient. Also, $PM_{2.5}$ not only had higher reported concentrations but is also considered one of the most dangerous pollutants for humans due to its small size and ability to travel deeply into the respiratory tract.[3] However, NOx pollution– which had similar concentrations as $PM_{2.5}$– did not seem to correlate as strongly. This may be because NO_X, while harmful, is generally considered less dangerous to human health than other forms of pollution, including ozone and particulate matter.

The American Heart Association has found that higher levels of air pollution may trigger cerebrovascular events through both long and short-term exposures.[54] Major studies conducted in the U.S., Europe, and Asia found that not only are higher levels of ozone correlated with a risk of premature death but also that lower levels of ozone can still cause serious harm.[50] A 2017 study in the United States found that older adults faced a higher risk of premature death, even when ozone levels remained well below national standards.[51] $PM_{2.5-10}$ has also been linked to illness, hospitalization, and death.[50] Researchers in a study of six U.S. cities tracked particle pollution and health outcomes from 1974 to 2009 and estimated that the U.S. could prevent around 34,000 premature deaths yearly by lowering annual particulate matter levels by 1 μg/m^3.[52] In the past three decades, the annual average of $PM_{2.5}$ exposure in Taiwan has ranged from 20 to 30 [μg/m^3] (four to six times the World Health Organization's guidelines).[14, 55] Taiwan's robust industrial sector and its geography and topography exacerbate the population's vulnerability to adverse pollution-related health effects.[15-17] Some studies have even suggested an interaction between pollutants.[27] It is plausible that higher correlations between O_3 and $PM_{2.5}$ pollution and stroke are related to both their high concentrations in the atmosphere and the known dangers they pose to human health.

Since the primary data regarding pollutants only spanned from 2010 to 2015, the findings could be more comprehensive in their adaptability. In the future, larger-scale investigations into the link between air pollution and stroke should be explored and analyzed for differences in the types of pollutants and other factors. Additionally, current data and trends should be followed longitudinally to understand the relationship between the variation in pollution and stroke mortality rates. As life expectancies grow, age-related medical conditions, such as stroke, will continue to impact a growing proportion of the global population. Simultaneously, experts are analyzing climate issues– including but not limited to air pollution– more and more for their public health implications. As such, an investigation into the topic of stroke and air pollution in Taiwan has global significance.

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