UTILISING ATMOSPHERIC SIMULATION AND DATA ASSIMILATION TO IMPROVE THE UNDERSTANDING OF HAZE EMISSIONS IN THE CHINESE REGION.

Xu Xuefeng 1*, Intan Irieyana Zulkepli 1, Mohammad Nizamuddin Inamdar 1, Aiman Al-odaini 1

1 Lincoln University College, Petaling Jaya, Malaysia.

*Corresponding author: Xu Xuefeng, Lincoln University College, Petaling Jaya, Malaysia.

ABSTRACT

Haze emissions continue to be one of the main difficulties for the environment in China. They are harmful to the environment, people's health, and the economy. The rapid growth of cities, the expansion of industry and the increasing energy demand have all increased fine particulate matter (PM) emissions. This has caused a broad haze to form repeatedly in numerous areas. Even though air quality has improved because of measures to cut down on emissions, haze is still a concern. This indicates how complicated the causes of haze are. Everyone must recognise the strong link between haze emissions and weather conditions since haze episodes continue even if the government tries to make the air cleaner. This study suggests that combining atmospheric models with data assimilation might help to understand how haze emissions change throughout China. The study used satellite observations to address uncertainties in emission inventories and climate data using sophisticated atmospheric models to depict the transport, transformation, and origin of pollutants. A stratified sample of 452 respondents from diverse professional backgrounds was used in the quantitative approach. The SPSS 25 study which includes ANOVA and factor analysis shows strong links between haze severity and weather elements including temperature, humidity, speed of the wind and airflow pressure. Simulation and data assimilation work together to develop fuzzy behaviour models that are more precise and dependable. This allows individuals to grow better at making predictions. This all-encompassing strategy provides Chinese researchers with practical tools to make comprehensive laws that would help lessen the negative consequences of haze emissions on the environment and human health.

Keywords: Atmospheric simulation; data assimilation; haze emissions; meteorological conditions; air quality.

INTRODUCTION

Rapid urbanisation has taken place in the Chinese region over the last few years which has caused a notable public health issue like haze emissions that the residents are presently dealing with. These emissions are generated by the swift increase in air pollutants in the environment. These emissions are extremely hazardous to public health as substantial portions of particulate matter can lead to devastating effects in ecosystems as well as on human health. In response to this major issue, the Chinese government invested approximately 63.30 billion

RMB between 2013 and 2018 in initiatives for mitigating air pollution and enhancing public health (Li et al., 2021). Even though the air quality has improved a lot due to these initiatives, there are still occasional haze episodes which trigger the pollution scale of the region. This denotes that China is going to suffer from these haze issues for a long time if preventive measures are not taken properly. Atmospheric processes such as weather fluctuation, chemical transformation and emission from coal or industrial products initiate the occurrence of haze episodes in the Chinese region. However, due to the emergence of data assimilation methods and atmospheric solutions, answers to these challenges have become transparent. These technology tools allow researchers to figure out when haze occurs and where it comes from which may help them produce methods of ensuring haze emissions happen less often. Using these models may help us better understand how contaminants evolve, spread, and build up. These simulations may assist in clarifying how air contaminants originate and spread (Zhang et al., 2020). Nevertheless, if there are doubts about where emissions originate from or how the weather is, these models may not be as precise. Therefore, merging data from ground monitoring networks and satellites is required to provide an additional choice. This can help in reducing mistakes in the model and make the coverage more accurate in terms of distance and time which leads to a better and more reliable report. Therefore, researchers who employ simulation and data assimilation together can develop a more evident and clearer picture of haze emissions than others.

BACKGROUND OF THE STUDY

Due to factors such as increasing vehicle emissions, growing urbanisation and industrialisation, haze emissions have emerged as a prominent environmental concern in China in the last few decades. In the last few decades, increasing urbanisation and industrialisation as well as growing vehicle emissions have ascended as significant environmental issues in China which cause haze emissions. The high concentration of PM during haze episodes is responsible for lowering air quality. This harms the well-being of human beings as well as the entire environment in a dangerous way. China's air quality demands the implementation of measures to mitigate the pollution as it fails to meet the interim Target-1 guidelines provided by the World Health Organisation. Adopted at all levels of government, these programmes aim to decrease the frequency and time limit of extreme air pollution events in China. They may impose limits on private automobiles, temporary shutdowns of high-pollution businesses, and prohibitions on outdoor activities in the construction sector. In 2015, it was estimated that 1.1 million people died being in exposure to higher levels of PM over an extended period (Feng & Wang, 2020). Researchers in China have taken advantage of the situation of these haze occasions to study the chemical and physical processes of haze emissions in the atmosphere as they have already accumulated a significant amount of knowledge regarding PM pollution and its connection with the meteorological conditions of the region. Due to the increasing prevalence of haze emissions across the Chinese region and their intensity, the local and central governments of China have executed several measures to improve the air quality and public health. Although the generation of primary PM from industries has significantly reduced due to government measures, the production of secondary PM from gas emissions remains a major concern and continues to contribute to poor air quality. Using these modern techniques, this research aims to learn more about the meteorological causes of haze emissions in China which will lead to greener and more sustainable cities.

PURPOSE OF THE RESEARCH

This research aims to explore the utilisation of atmospheric simulations and data assimilation to improve the comprehension of haze emissions in China. In an overly complicated and quickly shifting atmospheric environment, the research aimed to illuminate the urgent difficulties faced by institutions and legislators in controlling haze pollution. Determining emission sources, chemically transforming pollutants, dealing with weather unpredictability, transporting pollutants across regions, and limits for tracking frequency are all aspects that contribute to these issues. Finding connections between emissions and pollution episodes was one objective of the study which looks at how assimilation methods might combine observational data with simulation models to imitate pollutant behaviour. Several factors underscore the importance of this endeavour. Policymakers have access to inferior material and less trustworthy haze evaluations due to regional disparities in emission sources and monitoring networks. Institutions in under-resourced regions need to work harder to enhance the atmosphere and overall wellness since haze management is more complex in areas without enough infrastructure than in metropolitan areas with sophisticated surveillance systems. This study sought to address these challenges by combining real-time observational data into high-resolution atmospheric standards through data assimilation methods.

LITERATURE REVIEW

The roles of meteorology and emissions have been clarified in several research. To assess how emission control strategies affect air quality, chemical transport models are often used. The limitations of both models and emission inventories mean that simulations cannot always capture every detail of the actual world. To evaluate changes in meteorology and the impact of emissions, statistical analysis is another popular approach. Efforts to comprehend China's haze emissions have depended on data assimilation and atmospheric simulations. To explain how well WRF-Chem and neural network algorithms can imitate haze episodes in eastern China's most polluted areas, the researcher conducted simulations of visibility patterns in the Chinese provinces (Zong et al., 2020).

Increased humidity tends to promote the formation of aerosols which enhance the haze emissions in a hazardous way. On the other hand, fierce winds prevent the pollutants from dispersing in the atmosphere and decrease the severity of the haze episodes. Moreover, temperature also has a significant impact on haze emissions in the Chinese region. In this context, a researcher explained the utilisation of real-time data from the ground monitor networks to enhance the prediction level of these models with the help of a chemical transport model to predict the variations of PMs more accurately during haze emissions (Chen, 2021). Research works that used the distribution of source models along with the atmospheric simulation chambers helped determine the local and regional factors which have the most impact on haze emissions. These have allowed to generate a more accurate result. The preventative systems of these models have enabled pollution predictions to have better real-time solutions as the models are integrated with atmospheric simulations and data assimilations (Cao et al., 2023). On the other hand, insufficient weather data and unclear inventories of pollutants are common limitations of simulations employed in isolation. In response, data assimilation methods were developed to include LiDAR data, terrestrial measurements, and satellite imagery into models. By enriching the process's spatial and temporal resolution, researchers can make sure that our simulations are more precise representations of the Chinese region (Jain et al., 2022).

RESEARCH QUESTION

What is the impact of meteorological conditions on haze emissions in the Chinese region?

RESEARCH METHODOLOGY

Research Design: To better understand haze emissions in China, this study used a quantitative research approach to identify how atmospheric simulation and data assimilation should be used. After collecting the data, the researcher processed it via SPSS 25. To include demographic and project-related data, the researcher used descriptive statistics. To identify the kind and scope of the associations, researchers used inferential statistics such as probability ratios with 95% confidence intervals. For statistical purposes, a p-value below 0.05 was deemed important. To validate the information and identify statistically distinct groups, the researcher used a mix of component analysis and analysis of variance.

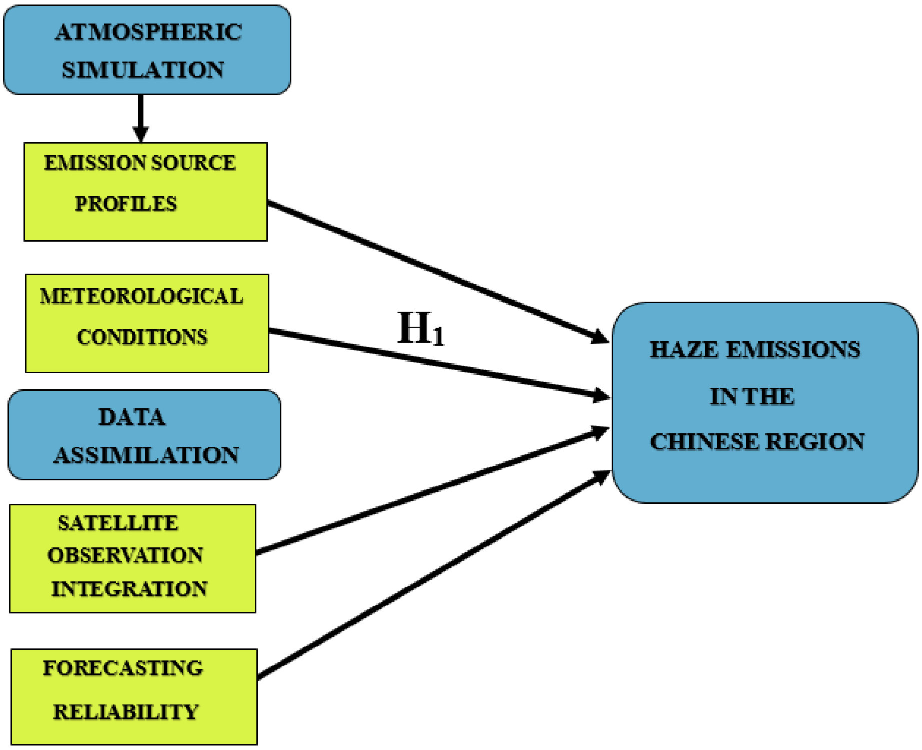
Sampling: The researcher used stratified sampling to gather data for the study. The study requires 412 participants according to Raosoft's sample size estimations. To reduce the response rate, the researcher randomly distributed 550 questionnaires to different strata. Following, 509 questionnaires were returned to the researcher. With 57 respondents giving incomplete or wrong answers, the total number of valid responses was 452.

Data and Measurement: The main method of data collection was the use of scheduled questionnaire surveys. Part, one included the researcher asking participants about their demographics and what professions they had. The researcher asked for their thoughts on several topics related to haze emissions using a five-point Likert scale in the second part of the survey. All sorts of endeavours and duties were included due to stratified sampling. The secondary data included in the research was mostly culled from academic publications, company documentation, and internet sources.

Statistical Software: The researcher used SPSS 25 and Microsoft Excel for statistical analysis.

Statistical Tools: Several demographic and project-related characteristics that are distinct to strata have been more clearly identified with the help of descriptive analysis. Examples of inductive statistical approaches are analysis of variance (ANOVA) for comparing groups, factor analysis for ensuring the reliability of measurements and their theoretical validity, and 95% confidence intervals for odds ratios.

CONCEPTUAL FRAMEWORK



RESULT

Factor Analysis: The goal of Factor Analysis (FA) is to discover previously unseen relationships among publicly available data. When straightforward visual or psychological indicators are not accessible, regression results are often used for assessments. Finding potential weak spots, breaches and obvious linkages is the main objective of simulation. Data gathered from multiple regression analyses are evaluated using the Kaiser-Meyer-Olkin (KMO) test. Both the mathematical model and the variables used to estimate it are trustworthy. The data may show that there are duplicates. The data becomes more legible when the proportions are reduced. Assigning a number between zero and one, KMO aids the investigator. A sufficiently big sample population is indicated by a KMO value between 0.8 and 1. Here are the certification requirements given by Kaiser: Unlike the usual range of 0.60 to 0.69, the absurd numbers fall between 0.050 and 0.059. In middle grade, a range of 0.70 to 0.79 is common. A score between 0.80 and 0.89 on a quality scale. The interval from 0.90 to 1.00 is considered excellent. The results of Bartlett's test of Sphericity are as follows:

Approx. chi-square = 3252.968

df = 190

sig =.000

Table 1. Testing for KMO (Kaiser-Meyer-Olkin) Sampling Adequacy Measure and Bartlett's Test.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.922
Bartlett's Test of Sphericity	Approx. Chi-Square	3252.968
	df	190
	Sig.	.000

Fundamentally, this allows claims that are related to sampling. The correlation matrices were assessed for significance using Bartlett's Test of Sphericity. At 0.922, the Kaiser-Meyer-Olkin statistic shows that the sample size is enough. A p-value of 0.00 is seen when Bartlett's Sphericity test is conducted. It can be assumed that the correlation matrix is not an identity matrix since Bartlett's Sphericity test came out positive.

INDEPENDENT VARIABLE

Atmospheric Simulation: Atmospheric simulation is a scientific domain that uses computer models to replicate how the atmosphere behaves over Earth. These simulations which consider biological, chemical, and physical processes in the atmosphere may help humans by helping them better understand and predict the weather, air quality, and climate change. Atmospheric simulation is essential for understanding haze emission in the atmosphere as it helps researchers to explore the processes in which pollutants are released, developed, and scattered across the atmosphere. These processes are important as they allow to understand the sources of the haze and classify their types in terms of natural, industrial or vehicle fumes. The power of these models to forecast the diffusion of pollutants across different geographies and meteorological conditions is indispensable for researching the persistence of haze events in the Chinese regions (Sun et al., 2021). Atmospheric simulation chambers like those in the EUROCHAMP network are extremely helpful research tools for studying the physical and chemical processes that occur in the air. They are useful in many different situations such as cloud micro physics, air pollution, climate change, preserving cultures and the well-being of individuals (Doussin et al., 2023).

FACTOR

Meteorological Conditions: Meteorological conditions include climate variables like air pressure and humidity and have important effects on a certain area. There are several reasons why it is so crucial to understand climatic trends. They help people plan activities and be ready for disasters which affect daily weather predictions. Climatic conditions are the most significant factors when it comes to air quality, visibility, haze production, and pollution. To keep a watch on and investigate these positions, sensors and satellites across the world gather data. This information is needed for laws, emergency preparation and supervising the environment (Liu et al., 2020). These weather conditions may help the researchers to identify the swift changes in the weather as well as its short and long-term trends. Since China is so vast and has so many distinct types of land such as beaches, high plateaus and hilly areas, the weather there is completely different from place to place. All around the country, these factors have a major impact on the weather, atmosphere, and ecological issues.

DEPENDENT VARIABLE

Haze Emissions in the Chinese Region: The seasonal shifts are brought to light by the fact that haze emission is more severe during the fall and winter than it is during the summer. The regional aggregation effect is another element that contributes to the expanded concentration of haze pollution in some regions that have had the greatest economic development. The China Meteorological Administration declared that the average number of days that China's haze emissions emerged in 2013 was the highest since 1961. This caused several problems including aircraft delays, the temporary closure of scenic areas and a soaring rate of respiratory diseases. There is a disastrous impact that extreme haze emission has on the ecology, the atmosphere and all elements of human life that are of considerable significance. As an overall principle, it is considered that industries such as agriculture and transportation are more susceptible to the effects of the environment and the weather. A pattern of severe haze emission episodes indicated by extremely high PM mass loading (ranging from 100 to 1,000 $\mu g{\cdot}m^{-3}$) and comprehensive temporal and geographic coverage has been repeatedly seen in northern China especially in the North China Plain (NCP). In January 2013, there was a strong haze that impacted almost 800 million people and a total area of around 1.3 million km^2. The haze remained for a month (Zhang et al., 2020). The major variables that influence the frequency and severity of haze in northern China include high emissions of gaseous particulate matter precursors, initial particles from various sources, effective production of secondary particulate matter, regional transportation, and unfavourable weather conditions.

Relationship between meteorological conditions and haze emissions in the Chinese region: Variations in meteorological conditions are likely to result in a diversity of haze formation methods in distinct parts of China. Haze emission is mostly caused by inappropriate combustion in northeast China, a region that has a prolonged warm season (mid-October to mid-April). During the winter haze that occurs during the harvest season in northeast China, there are extremely prominent levels of organic aerosols. In northeast China, urban areas had an annual aerosol optical depth that was about 3.7 times more prominent than rural regions because of the regional haze during winter (Yang et al., 2025). Haze emission is impacted by meteorological conditions and pollution. To evaluate pollution control methods, it is crucial to understand the consequences of changes in the weather and decreases in emissions. High-pressure systems also help stabilise the atmosphere which prevents vertical mixing and keeps pollutants near to the surface. On the other hand, rain or storms may help remove haze by washing away pollutants. The weather has a big effect on how strong and long haze events occur (Qu et al., 2020). Haze dynamics are influenced by wind in two distinct ways. Pollutants are trapped closer to the surface when breezes are weak or slow making haze conditions worse. On the other side, air quality may momentarily improve when high winds spread contaminants across broader regions.

Proceeding from the previous discussion, the researcher formulated the following hypothesis to investigate the impact of meteorological conditions on haze emissions in the Chinese region.

"H_{01}: There is no significant relationship between meteorological conditions and haze emissions in the Chinese region."

"H_1: There is a significant relationship between meteorological conditions and haze emissions in the Chinese region."

Table 2. H1 ANOVA Test.

ANOVA					
Sum					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	39987.323	122	3156.221	870.681	.000
Within Groups	991.236	329	3.625		
Total	40978.559	451			

This investigation yields substantial results. The F-value of 870.681 indicates statistical significance at the.000 p-value which is lower than the.05 alpha level. This signifies that the "H_1: There is a significant relationship between meteorological conditions and haze emissions in the Chinese region" is accepted, and the null hypothesis is rejected.

DISCUSSION

The outcomes of this study showed the compact link between weather and haze emissions in the Chinese region. Changes in humidity, air pressure, wind speed, and temperature significantly impact haze occurrences according to the data. The study demonstrated that weather situations such as heat, air pressure, humidity, and other related factors play a significant role in haze formation and dispersion. High humidity and turbulent weather conditions affect the intensity of the haze. Static weather encourages the scattering of pollutants across the region, whereas temperature inversions help entrap them close to the surface. These results supported the earlier research works which highlight the meteorological conditions influencing haze emissions in the Chinese region. In this context, the blended use of atmospheric simulations and data assimilation helps deliver insightful information regarding the mitigation of haze emissions. These methods normally provide more accurate and reliable forecasts of haze along with strategies for its mitigation. This allows the researchers to obtain improved early warnings of haze which is regarded as a notable factor for public health.

CONCLUSION

The research concluded the substantial connection between climatic conditions and haze emissions in Chinese areas with a primary emphasis on North China. The study's results showed that meteorological conditions like heat, temperature, wind, and other factors have a rapid impact on the development and distribution of pollutants as well as the stability of haze emissions in the area. In this context, the study provided a transparent understanding of the meteorological factors that impact the frequency of haze emissions by integrating atmospheric simulation and data assimilation. The outcome of the study highlighted the importance of considering weather conditions to improve the air quality of the region as they have an immediate influence on the intensity of haze episodes. Policymakers in this region need to incorporate weather forecasting in their plans for haze emissions to ensure that the regulations they put in place work as well as possible. The study offered a thorough analysis of the significant influence of meteorological conditions on haze emissions in the Chinese region. It also facilitated a methodological framework that incorporates emission reduction strategies with weather forecasting to alleviate pollution and enhance public health.

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