The Causes and Countermeasures of Sand-dust Weather in Northern China

Yiran Zhang*

RCF Experimental School, Beijing, 100102, China

*Corresponding author's e-mail: zhangyiran2025@126.com

Abstract. In recent years, phenomena such as floating and sinking dust, blowing sand, and sandstorms have frequently occurred in northern China, causing significant harm to society. Understanding dust weather and finding ways to mitigate its effects have garnered considerable attention. This paper first examines the causes of dust weather in northern China, including strong winds, dust sources, specific climatic conditions, and human activities. The environmental and social impacts of dust weather are analyzed from two perspectives: harm and benefit. Based on this analysis, the paper proposes countermeasures for dust weather management in northern China and outlines future research directions to provide a reference for subsequent studies.

Keywords: sandstorm; countermeasures; dust source; northern China

1 Introduction

Dust weather is a meteorological phenomenon characterized by the suspension of sand and dust particles in the atmosphere, resulting in air turbidity and diminished visibility [1]. This phenomenon is frequently observed in arid and semi-arid regions, with northern China being particularly susceptible. The spring season is the most conducive to dust weather, accounting for 77.5% of the annual occurrences of such events [2]. Notably, April records the highest frequency of sand-dust weather outbreaks in the country. Between January and April 2023, a total of 12 dust weather events were documented in northern China, representing a significant increase compared to previous years.

The classification of dust weather is categorized into five levels—floating dust, blowing sand, sandstorm, strong sandstorm, and extremely strong sandstorm—based on horizontal visibility and wind power intensity, as illustrated in Table 1.

Table 1. Characteristics of different dust weather

Classification	Visibility (km)	Wind speed (m/s)
Floating dust	<10	≤3.0
Blowing sand,	1-10	3.1~10.7
Sandstorm	<1	10.8~17.1
Strong sandstorm	<0.5	17.2~24.4
Extremely strong sandstorm	<0.05	≥24. 5

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Dust storms significantly contribute to atmospheric pollution, exacerbate soil degradation, and result in various adverse effects such as traffic disruptions, structural damage to buildings, and agricultural losses. These consequences pose substantial threats to both the national economy and public health. This paper primarily examines the causes of dust storms in northern China, summarizes their impacts on the environment and human society, proposes strategies for dust storm mitigation, and anticipates future research directions in the field of dust storm studies.

2 The Cause of Dust Weather in Northern China

2.1 Strong Winds

Strong winds are a dynamic factor in the generation and long-distance transport of sand and dust. When the wind speed near the ground exceeds the threshold required to initiate dust movement, dust particles detach from the surface, leading to the release of sand and dust. Variations in the wind energy environment across different regions result in varying intensities of wind-blown sand activities. These activities, in turn, influence the transport height, quantity released, and transport distance of sand and dust materials, as well as the characteristics of wind-blown sand particles [3]. Consequently, these factors affect the severity of sand-dust weather events. In northern China, the occurrence of sandstorms is positively correlated with both the number of windy days and the wind speed during the same period. Furthermore, the unstable atmospheric conditions prevalent in spring facilitate increased wind speeds, thereby providing a source of energy for the onset of dust weather [4]. For instance, in March 2021, a widespread occurrence of severe dust weather was reported in northern China. During this event, strong winds were generated by a significant pressure gradient between a robust Mongolian Cyclone warm low-pressure system and a large cold high-pressure system. Wind speeds exceeding grade 8 were commonly recorded in Mongolia and Inner Mongolia, China, thereby creating favorable dynamic conditions for the development of intense dust weather [5].

2.2 Abundant Dust Sources

The presence of abundant dust sources is a critical material condition for the occurrence of dust weather phenomena. Global dust storms predominantly arise in desert regions and adjacent arid and semi-arid areas [4]. In China, the distribution of dust sources is relatively stable, categorized into domestic and international sources. The interior of Asia is characterized by a temperate continental climate, which is marked by low precipitation and sparse vegetation, with extensive areas of Gobi and desert landscapes [5]. These regions exhibit a significant expanse of bare surfaces, elevated temperatures, limited precipitation, and an overall dry climate, all of which contribute to the availability of substantial sand sources for dust weather events [2]. In China, the primary dust sources are located in Inner Mongolia, Xinjiang, and the deserts adjacent to the China-Mongolia border. International dust sources are chiefly found in the desert regions of southern Mongolia and southeastern Kazakhstan. In southern Mongolia, factors such

as overgrazing have led to a rapid decline in vegetation, resulting in desertification affecting 72% of the country's land area. Additionally, seven regions in eastern Kazakhstan have experienced desertification exceeding 5,000 square meters. A notable sandstorm occurred in Ordos City during the spring of 2021, with the primary dust originating from Mongolia. Furthermore, the Kubuqi Desert and Mu Us Sandy Land in Ordos serve as persistent sand sources that facilitate the formation and intensification of sandstorms [6]. An analysis of two dust weather events in the Baoding area during March and April 2021 indicates that the dust originated from the northwest in both instances. In the earlier event, the dust traveled from northern Mongolia to Lake Baikal, moving southeast through Inner Mongolia before impacting Hebei and subsequently affecting the Baoding area. During the dust weather event in Baoding in April, dust at altitudes of 500 meters and 1,000 meters was traced back to western Mongolia, while dust at a lower altitude of 50 meters was sourced from western Inner Mongolia [7].

2.3 Special Climatic Conditions

In northern China, spring precipitation is relatively low, accompanied by a noticeable increase in temperature. These dry and barren surface conditions create a substantial material basis for the occurrence of large-scale dust storms. Research indicates that the duration of sandstorms in northern China exhibits a negative correlation with both spring precipitation and precipitation from the previous year; specifically, greater precipitation is associated with shorter durations of sandstorms [8]. Conversely, the duration of sandstorms is positively correlated with spring temperatures and temperatures from the preceding year. Fluctuations in spring temperature can induce local thermal instability and updrafts, which facilitate the occurrence of sandstorm events. Additionally, vegetation coverage plays a critical role in influencing the frequency of sand and dust disasters in northern China; areas with dense vegetation can effectively mitigate the impact of such disasters. In 2023, the incidence of dust storms in China exceeded typical levels. This increase can be attributed primarily to reduced precipitation in southern Mongolia and northwestern China compared to the same period in previous years, coupled with elevated temperatures. These conditions have led to diminished snow cover and the thawing of the frozen soil layer, thereby providing loose dust material conducive to the formation of dust storms. Furthermore, the atmospheric circulation patterns in northern China have favored the movement of cold air, with the frequent southward displacement of cold air masses creating conditions that facilitate the transport of sand and dust [2].

2.4 Human Factors

Unreasonable human activities are significant contributors to the formation of sandstorms. Practices such as overgrazing, excessive land reclamation, deforestation, and the extensive use of land resources destroy surface vegetation, exacerbate land desertification, and create conditions conducive to the formation and development of sandstorms [2]. Additionally, the over-exploitation of groundwater lowers the water table, leading to the desiccation of original beaches, lakes, and marshes, which may ulti-

mately become barren land. As temperatures rise and the ground thaws, the exposed sand becomes highly susceptible to evaporation and gradually loosens, directly accelerating the formation and intensification of dust storms.

3 The Influence of Dust Weather in Northern China

3.1 Harm

Dust weather will bring strong winds and dust, which will cause harm to the environment and human society. The harm of dust weather is mainly reflected in the following aspects:

(1) Affecting traffic safety. Dusty weather, especially dust storms, can greatly reduce air visibility and cause traffic accidents. In addition, sandstorms can disrupt the normal takeoff and landing of aircraft, compromising flight safety. Severe sandstorms may bury roads, railways, and airports, posing significant threats to transportation infrastructure. For instance, dust storms have frequently caused delays and disruptions for passengers and freight on the Lanxin Line, while airports in Lanzhou and other locations have been closed multiple times due to dust conditions.

(2) Threats to human health. Dust storms elevate the concentration of inhalable particles in the air, which can lead to choking, eye diseases, respiratory tract infections, and other respiratory illnesses. Additionally, these conditions can increase the risk of cancer and mortality rates [8].

(3) Cause economic losses. Intense winds can devastate agricultural fields, eroding crops and resulting in significant losses for both agriculture and animal husbandry. Particularly severe dust storms can also damage buildings and lead to substantial economic repercussions. For instance, in 1993, a major sandstorm in Gansu and Ningxia caused 85 fatalities, 135 serious injuries, the destruction of 42,800 trees, and direct economic losses exceeding 200 million yuan [2]. In 2000, the direct economic losses attributed to sandstorms in Inner Mongolia reached 85.69 million yuan, with 77.4 million yuan lost in the agricultural sector [9].

3.2 Benefit

Although the dust storm can cause significant harm to the ecological environment and human society, it is a normal climatic phenomenon within the Earth's ecosystem. It is closely related to other environmental phenomena and can have beneficial effects on certain natural factors.

(1) Alleviating acid rain: The northern region of China is relatively industrialized, resulting in significant emissions of sulfur dioxide and nitrogen oxides into the atmosphere. However, acid rain is infrequent in this area, primarily due to low precipitation levels. Additionally, the frequent occurrence of dust storms in the northern region plays a crucial role. The dust is rich in alkaline ions, such as calcium ions. When these alkaline particles interact with acidic sulfur and nitrogen compounds in the air, they undergo a neutralization reaction, which inhibits the conditions necessary for acid

rain formation. Consequently, this process reduces the likelihood of acid rain in northern China.

(2) Mitigate climate warming. Dust particles in the atmosphere can enter the troposphere and stratosphere, reducing the solar radiation that reaches the Earth's surface and consequently lowering surface temperatures, creating a "parasol effect." Additionally, sand and dust particles are rich in iron and phosphorus, which are essential nutrients for marine organisms. When these particles settle in the ocean, they promote the growth of phytoplankton at the ocean's surface. This phytoplankton absorbs carbon dioxide from the atmosphere during its growth process, thereby helping to alleviate the greenhouse effect and mitigate climate warming [2].

(3) Alter the topography. Research indicates that the nutrients found on the island of Hawaii primarily originate from the Eurasian continent. Sandstorms originating from this region transport a significant amount of fine, nutrient-rich dust to altitudes of up to 3,000 meters, which subsequently settles in the Hawaiian area across the ocean. Over time, this accumulation has fostered an ecosystem in Hawaii that provides essential material conditions, resulting in the creation of stunning natural scenery. Additionally, dust storms have also contributed to the formation of the Loess Plateau in China. The loess and silt that comprise the Loess Plateau primarily originate from Central Asia, Mongolia, Xinjiang, Gansu, and other regions within China. The movement of the northwesterly winds over the past 8 million years, combined with crustal movements, has ultimately shaped the Loess Plateau, which spans approximately 400,000 square kilometers in China.

(4) Conducive to rainfall. Dust aerosols can serve as condensation nuclei or ice nuclei for clouds, interacting with them to alter their physical characteristics, life cycle, and cloud cover, ultimately leading to increased regional precipitation [10].

4 The Countermeasures of Dust Weather in Northern China

In general, dust storms, as a type of natural disaster, cause more harm than good and have a significantly negative impact on the world. The key to controlling sandstorms lies in eliminating the conditions that foster their formation. Among the two critical factors—sand dust and strong winds—controlling strong winds is particularly challenging. Therefore, it is more feasible to prevent and manage sand by reducing the sand source that contributes to sandstorms. The northern region should prioritize the improvement of farmland and the establishment of a desert shelterbelt system as soon as possible. In desert areas, planting sea buckthorn and other vegetation suitable for arid conditions can help create a ground cover layer. This layer reduces wind erosion caused by sudden gusts and stabilizes sandy soil, thereby preventing further land desertification [4]. Additionally, the global atmospheric system is an interconnected and interactive whole; dust storms in Northeast Asia can impact Mongolia and China, as well as downwind areas such as South Korea, Japan, and the North Pacific region. Therefore, it is essential to cultivate a sense of community with a shared future for humanity,

strengthen international cooperation, and encourage more countries to address the issue of sandstorms collaboratively, working together to combat desertification.

5 Conclusion

The occurrence of sandstorms in spring in northern China is positively correlated with the number of days with strong winds, wind speed, and temperature, but negatively correlated with precipitation. The deserts, including the Gobi Desert and those in Central Asia, Mongolia, and northwest China, serve as sources of sand for the dusty weather experienced in northern China. Unregulated human activities exacerbate the formation of dust storms. Dust storms can impact traffic safety, pose risks to human health, and result in economic losses. However, dust storms can also have beneficial effects, such as increasing precipitation, mitigating acid rain, altering topography, and limiting climate warming. Overall, the negative impacts of dust storms outweigh the positive effects. The key to controlling sandstorms lies in prevention and management strategies. Governments worldwide should enhance cooperation and collaborate to effectively control and prevent sandstorms.

6 Outlook

Dust storms have caused significant harm to human society, drawing considerable attention and prompting deeper research into this phenomenon. Future studies should concentrate on the following aspects:

(1) The mechanisms of dust formation, migration, and settlement remain unclear. This can be studied by integrating satellite remote sensing, ground monitoring, and model simulations to enhance the long-term observation and predictive capabilities regarding dust storms and their influencing factors, such as temperature, precipitation, wind speed, and soil moisture. This approach aims to provide early warnings and protective measures.

(2) A rational evaluation of sandstorms is essential for the scientific and effective protection and restoration of ecosystems. In the context of desertification control, it is important to focus on both proactive measures and the avoidance of harmful practices. Completely eliminating sandstorms is challenging, as it is difficult to maintain the normal functioning of global ecological systems. Therefore, future research should concentrate on how to appropriately manage the frequency of sandstorms while minimizing their detrimental effects.

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