

Fugitive dust: An overview of Environmental Concerns and Health Risks

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Fugitive dust is a serious environmental concern that can emerge when soil is mechanically disturbed, releasing fine particles into the air. The atmospheric particulate matter may contain different metals, influenced by natural or human-induced factors, posing health risks to humans. Research indicates that these suspended particles make up a considerable portion of PM₁₀ (particles with aerodynamic diameters below 10 micrometers) in both urban and non-urban regions. These fine dusts originate from diverse sources like roads, construction sites, agriculture, and combustion processes, potentially causing adverse effects on human health over both short and long periods.

Especially noteworthy is the need for prompt control of fugitive dust emanating from construction sites near residential areas and agricultural zones, as it profoundly affects human health. Studies reveal that PM₁₀ resulting from the erosion of road pavement due to studded tires triggers inflammatory responses in human cells comparable to those induced by diesel particles. Prolonged exposure to moderate PM₁₀ concentrations has been associated with severe health impacts, including a noteworthy decrease in the average life expectancy of a population by several months.

Unpaved road:

In India, around 34% of the total road network comprises unpaved or gravel roads. A significant portion of these roads connects rural farming communities to urban areas, while others lead to forests, mining fields, and timber hauls. Fugitive dust on these roads arises from the mechanical interaction between moving vehicles and crushed aggregates, primarily consisting of soil minerals with particle sizes below 10 μm (PM₁₀). According to a report by the Central Pollution Control Board, approximately 41 million short tons of PM₁₀ and 16 million short tons of PM_{2.5} particulates (size below 2.5 μm) are released into the air annually.

Unpaved roads contribute to 31% of PM₁₀, and agriculture accounts for 47% of this particulate matter.

Agriculture:

Enhancing agricultural mechanization stands as a key facet of agricultural modernization, playing a crucial role in India's sustainable agricultural development. The widespread adoption of mechanization has significantly boosted production efficiency, increased farmers' income, and contributed substantially to rural economic growth. However, alongside these benefits, challenges arise. In 2022, wheat and paddy cultivation covered 34.3 million and 38.4 million hectares, respectively, while other pulses and oilseeds expanded to

48.4 million hectares. During peak farming seasons, concentrated farmland operations lead to dust issues, especially during harvesting. Agricultural machinery, interacting with crops, generates dust particles that become airborne, posing health risks to operators, impairing visibility, and affecting sensors. This fugitive dust, under specific weather conditions, extends air pollution, contributing to inhalable particulate matter and impacting the well-being of agricultural workers.



Figure 1. (a) Unpaved road (b) Agricultural field

The creation of fugitive dust on unpaved roads and agriculture poses a substantial threat to the well-being, economy, and safety of both road users and residents in the surrounding areas. The inclusion of PM₁₀ and PM_{2.5} in this dust significantly affects the health of the public, livestock, vegetation, and aquatic life near unpaved roads, facilitating the transportation of allergens, spores, and microorganisms.

Impact on human health:

While some researchers link PM_{2.5} particulates to cardiovascular and respiratory issues, others connect PM₁₀ to higher hospitalization rates for ischemic heart disease and cancer. Inhaled atmospheric particles larger than 2.5 μm tend to deposit in the upper respiratory tract, while those



smaller than 2.5 μm can directly enter bronchioles and alveolar ducts. Elevated concentrations of inhalable particulate matter (PM₁₀) have been linked to diminished respiratory function and worsened respiratory disease symptoms. Different components of particulate matter, such as secondary organic aerosols, elemental carbon, nitrates, and ammonium, impact various diseases. For instance, organic and elemental carbon, along with nitrates, affect cardiovascular disease, while water-soluble elements like As, Cd, Cs, Pb, Sb, Tl, and Zn, and polycyclic aromatic hydrocarbons (PAHs) influence cancer risks. PM₁₀ entering lung tissue triggers defensive responses and the release of inflammatory mediators from cells like epithelial cells, macrophages, and fibroblasts, leading to lung diseases.

Recent data analysis by Wu *et al.* in 2020, using U.S. data, reveals a positive association between long-term PM_{2.5} exposure and increased COVID-19 risk. Specifically, a mere 1 $\mu\text{g}/\text{m}^3$ rise in PM_{2.5} correlates with an 8% increase in the COVID-19 death rate in the United States. For children and the elderly, finer dust particulates exacerbate heart and lung conditions, raising the risk of ailments like bronchitis, pneumonitis, wheezing, cardiac artery disease, and cardiac arrhythmias, potentially leading to death. Concentrated airborne fugitive dust not only degrades air quality but also hampers road visibility, heightening the likelihood of accidents, fatalities, and traffic disruptions.

Impact on Ecology:

Fugitive dust isn't a singular contaminant; it's a diverse mix of particles with differing sizes, origins, and chemical compositions. Beyond posing risks to human health, it actively engages in atmospheric processes through dry and wet deposition (rain, snow, frost, fog, etc.). Additionally, dust can absorb or scatter sunlight, diminishing visibility, weakening solar radiation, and influencing environmental thermal balance, subsequently impacting temperature and ecosystems.

Impact on climate:

Fugitive dust has a nuanced impact on Earth's climate. Aerosols, a type of particulate matter, possess a "parasol effect," absorbing and reflecting solar radiation, leading to a decrease in radiation reaching the Earth's surface and subsequently lowering the temperature. Conversely, like greenhouse gases, aerosols contribute to a "greenhouse effect," elevating Earth's temperature. Notably, aerosols have a shorter life cycle than greenhouse gases, making their concentrations more responsive to emission changes.

Dust suppression mechanism:

a. Hygroscopicity:

Hygroscopicity refers to a substance's capacity to absorb moisture from the surrounding

atmosphere. Hygroscopic materials, attracted to water, can maintain a damp and firm road surface, preventing fugitive dust erosion. Two classes of hygroscopic materials exist: chemical, which undergo a chemical reaction to absorb water (e.g., metal hydrides), and physical, which absorb water vapor through mechanisms like surface adsorption, condensation in capillaries, reversible crystal structure changes, and a combination of capillary forces and hydration of functional groups.

b. Agglomeration:

Agglomeration-based dust suppression involves introducing binding or cementing agents to dust particles. Agglomeration transforms small solid particles into larger granules, binding them together. This process, aided by adhesive forces from the binding agent, increases mass, making the particles less likely to become airborne. Examples of agglomeration-based dust suppressants include corn starch hydrogels, guar gum, chitosan, various surfactants, and oil-based substances.

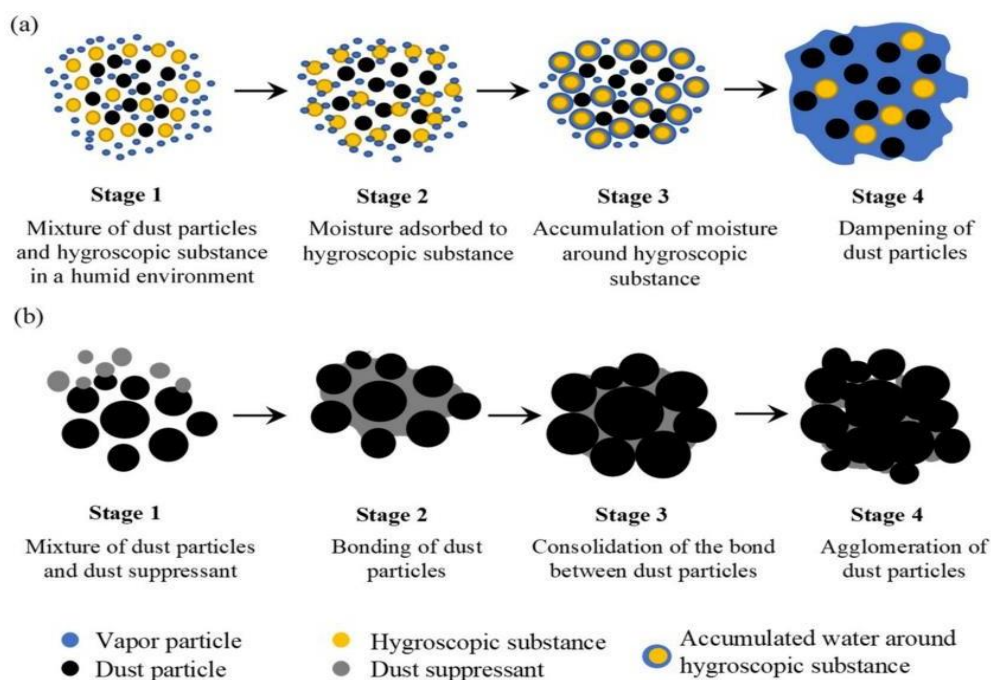
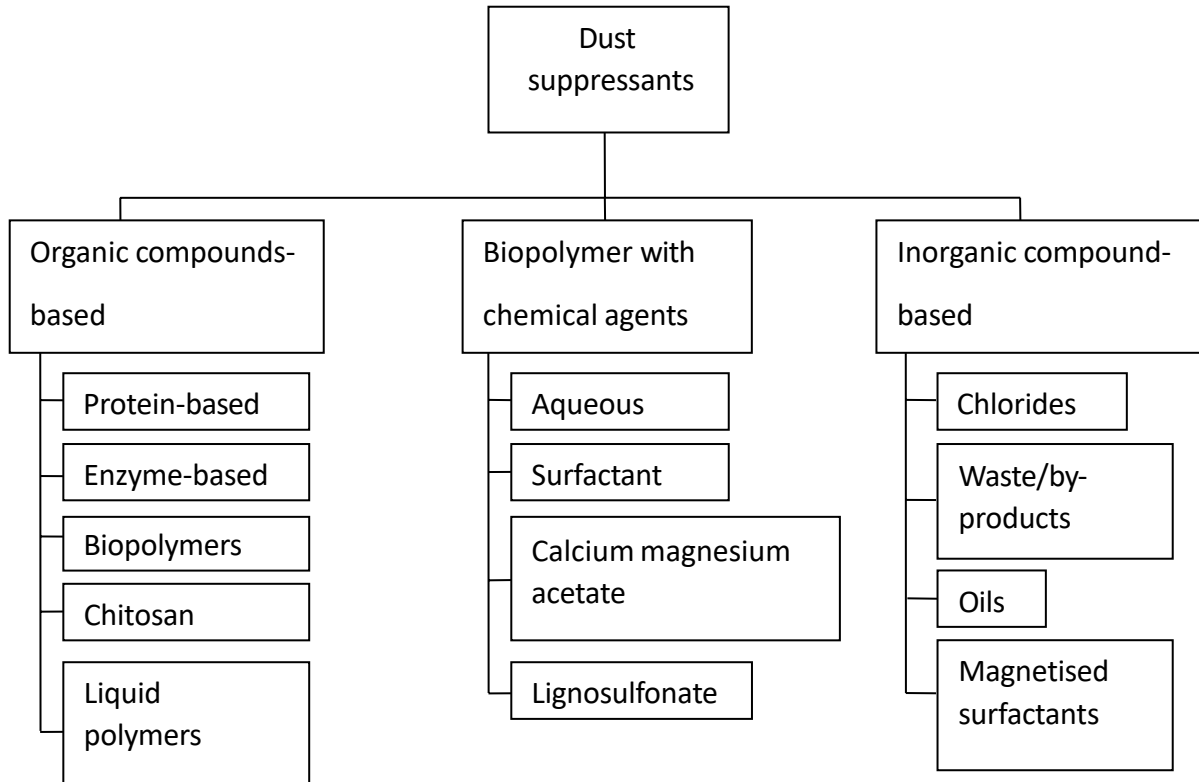


Figure 2. Dust suppression mechanisms: (a) hygroscopicity and (b) agglomeration

Various dust suppressants used to control the dust. Those have been categorized into three major types: (1) organic compound based, (2) biopolymer and chemical combination, and (3) inorganic compound-based dust suppressants.



Conclusion:

Fugitive dust, whether natural or human-made, poses significant threats to both the environment and human well-being. Unpaved roads are particularly susceptible to safety and health risks due to dust, prompting the use of dust suppressants. These suppressants vary in effectiveness based on factors like their physical and chemical properties, application methods, soil type, and environmental conditions. Addressing the complex and harmful nature of fugitive dust from agricultural machinery is crucial for safeguarding agricultural laborers and fostering a culture of safety. Scientific treatment of dust generated during agricultural harvesting not only protects production safety but also preserves the living environment in rural areas. This issue is a pressing concern in the ongoing green development of rural areas, directly tied to agricultural safety and hygiene culture.