Cloud Seeding: Weather Modification Technology

Definition

- Cloud seeding is a **weather modification technique** that **artificially induces rainfall** by dispersing certain chemical substances into clouds to encourage condensation of water vapour into raindrops.

☁ Scientific Principle

- Works on the principle that **water vapour condenses onto particles called Cloud Condensation Nuclei (CCN)**.
- The seeding agents act as **nuclei** around which moisture condenses to form droplets, eventually leading to precipitation.

Common Seeding Agents

1. **Silver iodide (AgI)**
2. **Potassium iodide (KI)**
3. **Dry ice (solid CO_2)**
4. **Liquid propane**
5. **Calcium chloride ($CaCl_2$)** — used in some Indian experiments (e.g., Solapur).

☁ Conditions Required for Effective Cloud Seeding

1. **Pre-existing Clouds:** Seeding cannot create clouds — it only enhances rainfall from existing ones.
2. **Tall, Moist Clouds:** More vertical development increases seeding effectiveness.
3. **Low Wind Conditions:** Prevents dispersal of seeding material before it acts.
4. **Appropriate Humidity and Temperature:** Ensures condensation and droplet formation.

⚙ Different Cloud Seeding Methods

Type	Technique	Key Feature	Example/Use
1. Hygroscopic Cloud Seeding	Salts like NaCl or $CaCl_2$ are sprayed using explosives into the lower portions of warm clouds.	Promotes condensation by providing large nuclei.	Used in **Solapur experiment**, Maharashtra.
2. Static Cloud Seeding	Chemicals like silver iodide crystals are dispersed into cold clouds.	Induces ice crystal formation that grows and falls as rain/snow.	Common in **hill regions**.
3. Dynamic Cloud Seeding	Aims to strengthen vertical air currents to enhance moisture uplift.	Leads to formation of more droplets → more rainfall.	Used in **large-scale experiments** in the USA, China.

Applications of Cloud Seeding

1. Increasing Rainfall

- Used in **drought-prone regions** to augment natural rainfall.
- Supports **agriculture and water security**.

2. Geoengineering & Climate Research

- Studied as a **climate engineering tool** to counter regional droughts or mitigate local warming.

3. Weather Regulation

- **Suppresses hail**, **disperses fog**, and can **modify cyclone intensity**.

4. Pollution Control

- Artificial rain helps **wash out pollutants** and **reduce particulate matter (PM2.5 & PM10)** concentrations in the air.

5. Aviation Applications

- Used to **disperse supercooled fog** near airports to improve visibility and **ensure flight safety**.

⚠ Limitations of Cloud Seeding

1. **Not a Drought Solution:** Can only supplement, not replace, long-term water resource management.
2. ☁ **Cloud Dependency:** Cannot work without moisture-bearing clouds.
3. **Environmental Concerns:** Silver iodide and other chemicals may contaminate water and soil.
4. **Weather Imbalance:** Excessive rainfall in unintended areas may cause **flash floods or soil erosion**.
5. **Health Impact:** Toxic compounds (like AgI) can harm ecosystems and human health.
6. **Potential Climate Effects:** Some agents may contribute to **greenhouse gas accumulation**.

Cloud Seeding Experiments in India

- **Karnataka:** Seeding done under “Varshadhare Project” for drought relief.
- **Maharashtra:** Solapur experiment using **hygroscopic seeding** ($CaCl_2$ flares).
- **Tamil Nadu & Andhra Pradesh:** Experiments during weak monsoon years.
- **Delhi (Proposed):** To mitigate **severe winter air pollution** through artificial rainfall.

Delhi Air Pollution: A Context for Cloud Seeding

Current Status

- Delhi experiences **hazardous air quality** every winter.
- In early **2025**, it was ranked **India’s 2nd most polluted city** (Centre for Research on Energy and Clean Air – CREA).

Major Causes of Delhi’s Air Pollution

1. **Vehicle Emissions**
    - Accounts for ~40% of winter **PM2.5** levels.
    - High diesel vehicle usage worsens emissions.
2. **Industrial Emissions**

- NCR industries emit **SO_2, NOx, and PM2.5**, particularly from power plants and manufacturing units.

3. **Construction and Demolition Dust**
   - Major source of **PM10**; poor dust control mechanisms increase coarse particulate matter.
4. **Waste Burning**
   - Open burning of garbage and plastic adds toxic pollutants.
5. **Stubble Burning**
   - Crop residue fires in **Punjab, Haryana, and Western UP** elevate pollution levels each autumn.
6. **Weather Inversion (Winter Inversions)**
   - A layer of **warm air traps cooler air** near the ground.
   - Pollutants remain suspended close to the surface, worsening smog conditions.

Why Cloud Seeding is Considered in Delhi

- To **artificially induce rain** and **wash pollutants** (especially PM2.5 and PM10) from the atmosphere.
- Acts as an **emergency short-term measure** to improve air quality during severe pollution episodes.
- Previous attempts (2018, 2023 proposals) faced technical and meteorological limitations due to **lack of suitable cloud conditions**.

Significance for UPSC

Prelims Relevance

- Concept of **weather modification** and **cloud seeding agents**.
- Basics of **particulate matter** and **air inversion phenomena**.

Mains Relevance (GS Paper 3)

- **Environment & Pollution:** Innovative technologies for pollution control.

- **Disaster Management:** Addressing drought and extreme weather.
- **Science & Tech:** Application of atmospheric sciences.

Way Forward

1. **Scientific Validation:** Need long-term, evidence-based studies on effectiveness.
2. **Environmental Safety:** Use eco-friendly seeding agents.
3. **Integrated Approach:** Combine with **emission reduction policies** and **green energy adoption**.
4. **Weather Forecasting Infrastructure:** Improve cloud monitoring through **Doppler radars** and **satellite data**.
5. **Public Awareness:** Clarify that cloud seeding is a **temporary supplement**, not a permanent solution.

In Summary

Cloud seeding is a scientifically innovative but limited tool for rainfall enhancement and pollution mitigation.
While it holds potential for **short-term relief**, sustainable pollution control in Delhi requires **structural reforms** in transport, energy, agriculture, and waste management.


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Qila Saifullah
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