# FEASIBILITY OF AUGMENTING WATER-RESOURCES THROUGH SEEDING OF CLOUDS

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## ABSTRACT

*During the recent drought conditions, which affected various parts of the country, Pakistan Meteorological Department (PMD) had initiated Cloud-Seeding Experiments from June 2000, to augment rainfall mainly over drought-hit areas of the country, In the first part of this paper. Science of Cloud Seeding has been discussed, which indicates that there are mainly two different methods of Cloud Seeding - Warm Cloud Seeding and Super-Cold Cloud Seeding. The physical basis for achieving the goal is very different from each method. For example, in warm cloud seeding, some hygroscopic seeding agents like common salt, Urea, etc. are used, whereas in the super cold cloud seeding, silver iodide or dry ice is used as seeding agent.*

*In the later part of the paper, equipments required for experiments have been discussed. Meteorologically equipped aircrafts, weather radars, satellite receiving equipment, synoptic weather charts and other weather-forecasting facilities are some of the main facilities required for the purpose. In the last part, results of 48 warm cloud experiments have been presented, out of which 30 were successful.*

## INTRODUCTION

Pakistan possesses diversified climatic conditions, ranging from hyper-arid to humid. Some areas receive meager amount of rainfall during the year, insufficient to sustain agriculture and to meet civic water-requirement. Frequent drought-occurrence is the common feature of these areas. The major drought-prone areas are located in Balochistan, Sindh, lower NWFP and Southern Punjab.

Under the directives of the chief Executive of Pakistan, received through Engineer-in-Chief, the Pakistan Meteorological Department has accepted the challenge to conduct experiments on cloud-seeding throughout the country so as to augment precipitation. The main objective of this project is to determine the feasibility of cloud-seeding in different parts of Pakistan, in order to increase rain/snowfall during both summer and winter seasons. A step forward on the way of weather-modification, the experiments on fog-dissipation and hail- suppression will also be conducted.

The science of cloud-seeding has made considerable progress since 1940. At present, research and experiments on cloud-seeding are going on in most parts of the world, using ever-advancing technologies. With the development of weather-modification science, two schools of cloud-seeding methodology emerged. One school embraced what is called the static mode of seeding, while the other favours what is called the dynamic mode of seeding. Both the static and dynamic modes of cloud-seeding will be used in Pakistan, through ground-based and airborne seeding technology.

Earlier, the Pakistan Meteorological Department had conducted cloud-seeding experiments in Balochistan, NWFP and Punjab, during 1953 to 1956, and had achieved encouraging results.

During a presentation on the subject by Engineer-In-Chief in June 2000, the Chief Executive of Pakistan approved, in principle, the undertaking of cloud-seeding experiments in Pakistan. The task was assigned to the Ministry of Defence, to conduct these experiments through Pakistan Meteorological Department, which Department accepted the challenge and availed of the services of Army Aviation and Plant Protection Department (of the Ministry of Food & Agriculture) for conducting these experiments.

On the directive of Chief Executive of Pakistan, PMD undertook the cloud-seeding Project, starting from middle of 2000, to augment summer-precipitation of warm clouds. During the first part, a total of 48 experiments were conducted. Out of these, 30 turned out to be successful and 18 failed. Four experiments failed purely due to technical problems with the aircrafts. All the results were analyzed, keeping in view the prevalent meteorological situation at the time of the experiments. Generally, areas under the



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influence of natural rains were avoided during the experiments. The second part of this paper would cover the cold cloud experiments from 15th December to 31st March, 2001.

## BACKGROUND OF CLOUD-SEEDING IN PAKISTAN

Pakistan possesses diversified climatic conditions, mostly Arid & Semi-arid. Some areas receive meager amounts of rainfall during the year, insufficient to sustain agriculture and to meet civic water-requirement. Conditions become vulnerable to drought if two rainfall seasons fail to yield, in succession. Pakistan had its worst ever drought, starting mid 1998 to mid of this year. Partial relief has been noted after monsoon 2001, while most of the western and southern areas of the country are still under influence of this drought.

The science of cloud seeding has made considerable progress in many parts of the globe since 1940. PMD being the pioneer organization in cloud-seeding experiments had conducted these experiments as early as 1953-55.

## SCIENTIFIC BASIS FOR CLOUD SEEDING

In 1946, dry ice was dropped into a stratocumulus cloud. Very quickly, the cloud was transformed into a swarm of ice crystals that grew & fell from its base, leaving behind a distinct hole in the cloud. If naturally occurring ice-forming nuclei had sufficient concentration in this cloud, they would have transformed its super-cooled liquid droplets into ice crystals themselves. In fact, the dry ice pellets counter-acted the dearth in natural nuclei by artificially creating ice-embryos. Introduction of dry ice or silver iodide in super-cooled clouds could initiate a precipitation process.

Super-cooled water droplets available in the atmosphere (clouds), and lacking ice-forming nuclei are supplemented through seeding. This seeding initiates the transformation of the super-cooled water into ice crystals, which eventually enhance the precipitation process.

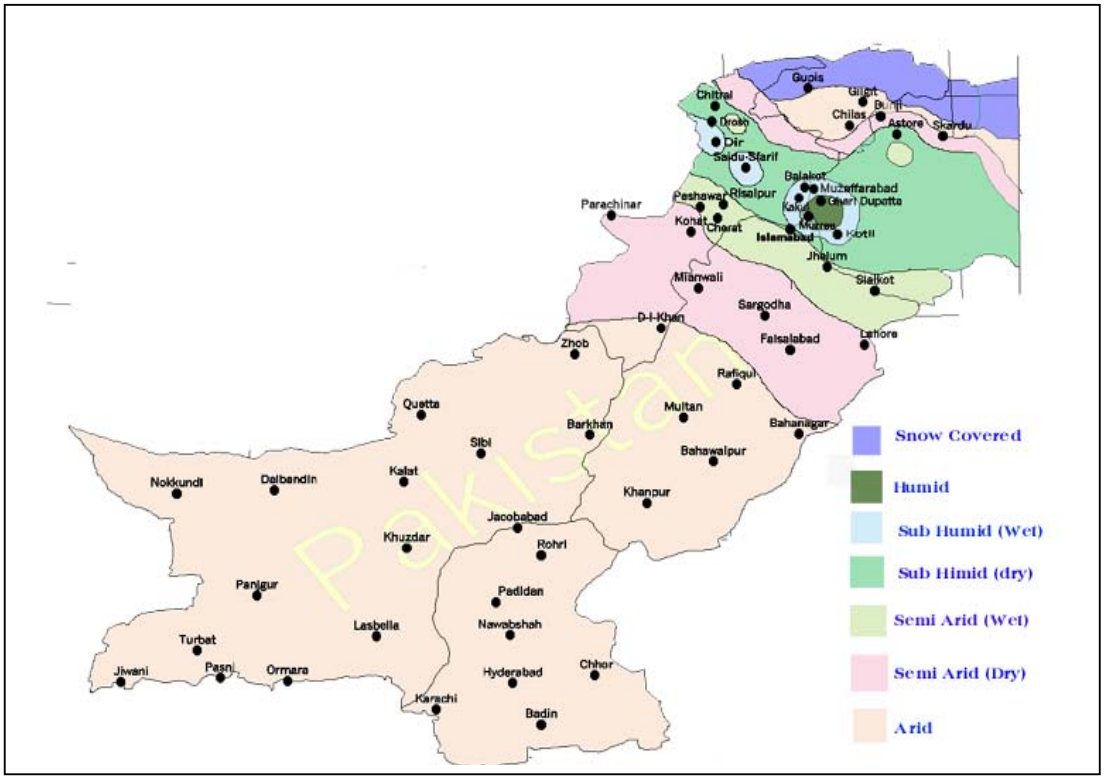



**Figure – 1: Broad Agroclimatic Zones of Pakistan On Annual Basis**

Warm clouds are seeded by any hygroscopic material, such as NaCl, CaCl, $NH_4NO_3$, Dust particle, Urea, etc, leading to nucleation of cloud-droplets. Through collision &

coalescence, the water droplets become big enough to fall onto the ground as rain.

## MODES OF CLOUD-SEEDING

Two different mechanisms can disrupt the microphysical stability and lead to larger cloud particles, which in turn have greater fall-velocities and may result in precipitation:

- *One* is direct collision & coalescence (Dynamic).
- *Second* process is interaction between super-cooled water droplets & Ice crystals in the clouds (Static).

**Dynamic Mode of Seeding**
(*To enhance rainfall by collision & coalescences*)

The concept of dynamic seeding is a physically plausible approach that offers opportunity to increase rainfall by much larger amounts than the static one. Warm rain formation is dominated by collision and coalescence among droplets. Collision and coalescence refers to the process, in which a large drop settling through the air at a high terminal velocity overtakes a small drop with a smaller settling velocity.

Clouds most favoured to create rain by collision and coalescence of warm clouds are warm based and maritime. To enhance rainfall from warm clouds by cloud-seeding, hygroscopic particles are introduced into the cloud that is large enough to function as embryos for collision and coalescence growth.

**Static Mode of Cloud-Seeding**
*(To increase the precipitation efficiency of Cloud/ Cloud System)*

Static mode of cloud-seeding is based on the concept in which ice crystals nucleate in a water- saturated super-cooled cloud, which will grow by vapour deposition at the expense of cloud droplets. The size of cloud, time available for cloud particle growth, and vertical velocity of air, constitute significant determinants for the growth of Precipitation-sized particles.

The size of cloud is controlled largely by the amount of moisture available, temperature profile & topography of the area. Droplets with radius less than 10 micron are formed in concentrations of hundreds per cubic cm. Terminal velocity of these droplets is < 0.3 cm/sec and are called colloidally stable.

Some details of methods and result achieved are given below:

## AREAS OF WEATHER MODIFICATION

**1. Different Areas**

- Fog dispersion
- Hail suppression
- Rain enhancement

**2. Different Cloud-Seeding Agents.**

- Silver Iodide
- Calcium Chloride
- Salt
- Dry Ice
- Liquid Carbon Dioxide.
- Dust

## *Rain-Enhancement through Cloud Seeding*

**1. Different Methods of Clouds Seeding**

- Airborne: By using Aircraft
- Ground base: By using Generator or Rocket Technology.

**2. Different Categories of Clouds**

a. *Warm Clouds:*
   - Base warmer than +10 C°
   - Top warmer than + 0 C°

b. *Super-Cooled Clouds:*
   - Base & Top colder than - 0 C°

**3. Types of Super-Cooled Clouds**

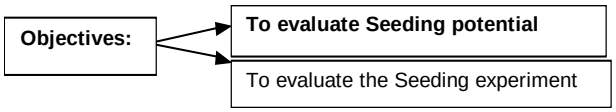
a. Deep Stratiform Clouds.
b. Shallow Stratiform Clouds.
c. Cumuliform Clouds

## METHODOLOGY FOR CLOUD-SEEDING OPERATION

- Identification of a suitable situation.
- Arrangement of an appropriate seeding agent.
- Successful transport and diffusion or direct placement of the seeding agent to the super-cooled regions of the clouds.
- Adequate time and super-cooled liquid and vapour must be available to provide precipitation-size particles.

- Eventual fall of rain on the ground in the desired location, before evaporation or being transported out of the target area.

## USES OF NUMERICAL MODELS IN WEATHER MODIFICATION




- To estimate the Seed-ability of the Cloud.
- To identify the optimum location to Seed.
- Quantity of Seeding material required.
- Best time to start Seeding.
- To distinguish operational and non-operational days.

## STATUS OF WEATHER-MODIFICATION EXPERIMENTS IN OTHER COUNTRIES

- *Japan* conducted Cloud Seeding of snow cloud in Central Japan for enhancing the snowfall in catchment areas of Dams in 1974 to 1997.
- *Mexico* 1997; Program for the Augmentation of rainfall in Coahuila was conducted and initial results were encouraging.
- *China* is successfully using rain enhancement techniques in their arid areas since 1990.
- *Thailand* is successfully using weather modification techniques since 1994.
- *Israel & USA*: They have done lot of research work in the field of weather modification during the last 40 years.

## PREVIOUS CLOUD-SEEDING EXPERIMENTS IN PAKISTAN

Pakistan Meteorological Department Conducted Cloud Seeding Experiments from 1953 to 1956.

**1. Seeding of Warm Clouds during Monsoon Season.**

In Mardan district of the NWFP, in 1953 by using two aircrafts loaned for the purpose from the PAF Academy Risalpur.

In central Punjab plains and hills, from ground generator in 1954.
Repetition of the above in 1955.
Repetition of the above in 1956.

**2. Seeding of Cold Clouds in the Winter Season**

From the hill top behind the Meteorological Institute, Quetta, in 1955.
Repetition of the above in 1956.

## RESULTS OF RECENT EXPERIMENTS

These results of 71 experiments recently conducted or shown in Tables-1 and 2. These show success rate of 65%.

## ECONOMIC BENEFITS OF CLOUD SEEDING

We may conclude that so far, the experiments on warm clouds have given reasonably good results, with 30 successes out of 48 experiments i.e. 63%.

The primary motivation for cloud-seeding is the Economic Benefits associated, viz:

i) Increased hydro-Electric power and agriculture production
ii) Salinity reduction
iii) Strengthened sky industries

- A study showed that an additional 10% of ppt over the growing Season would be expected to increase from revenue by $ 10M To $ 43M.
- Another study in U.S.A showed that added rainfall of 20mm In June – July and 30 mm for June – August would increase the Economy by over 0.5 billion.
- The other direct benefit is from the augmentation of Snowfall, which results in additional stream-flow for Generation of hydro- electric power and increased irrigation water.

**STATISTICS OF RESULTS**

| **Table - 1: Phase-1 (Seeding of Warm Clouds)** | |
|---|---|
| Total experiments conducted: | 48 |
| Highly successful | 30 |
| Limited success | 14 |
| Failure due to technical reasons | 4 |

| Table - 2: Phase-2 (Seeding of Cold Clouds) | |
|---|---|
| Total experiments conducted: | 23 |
| Successful | 9 |
| Limited Success | 6 |
| Failed | 8 |

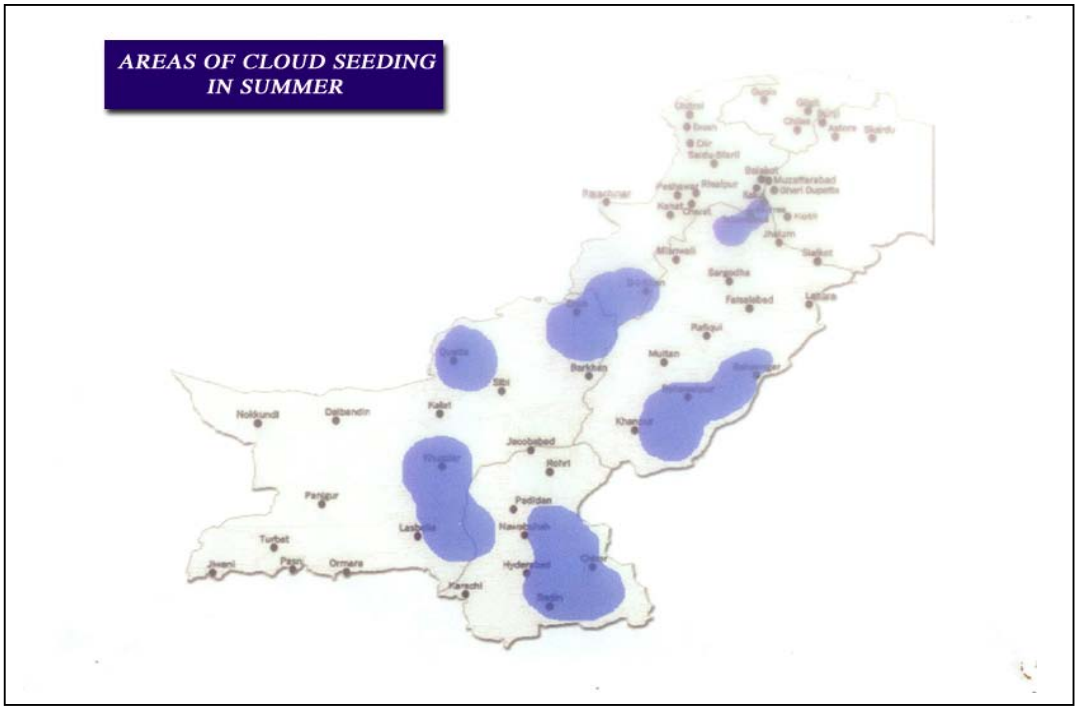



**Figure - 2: Areas Covered By Cloud Seeding Experiments During Recent Drought In Summer**

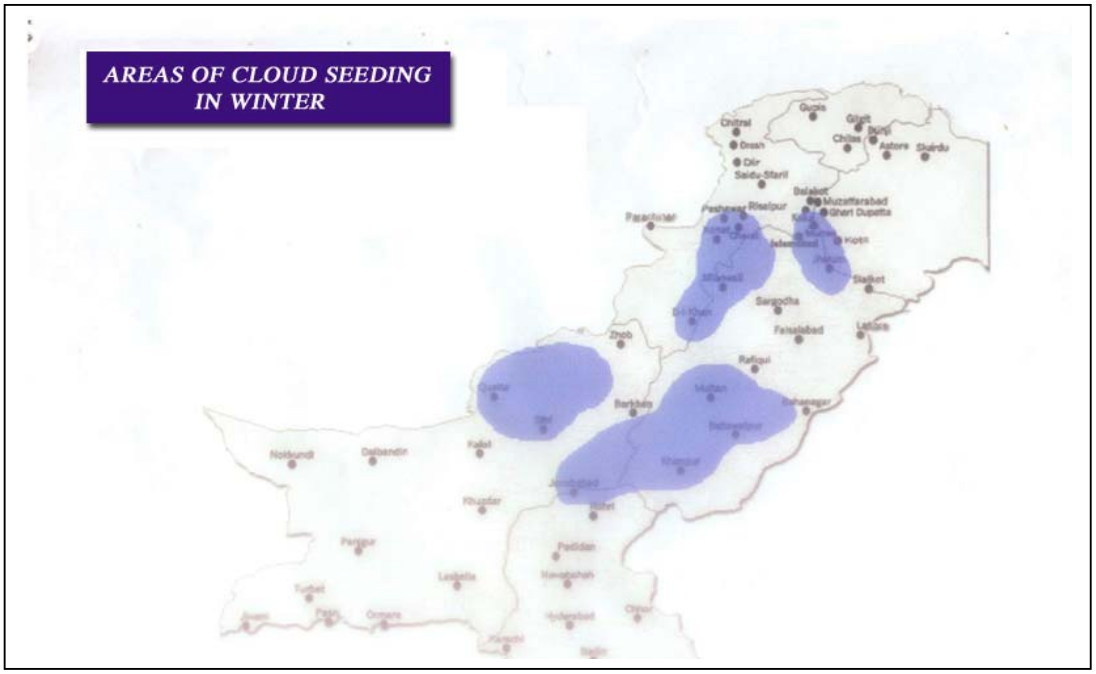



**Figure - 3: Areas Covered By Cloud Seeding Experiments During Recent Drought In Winter**