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Seeding Water Security: Rainfall Enhancement in the UAE's Water Portfolio and Diplomacy

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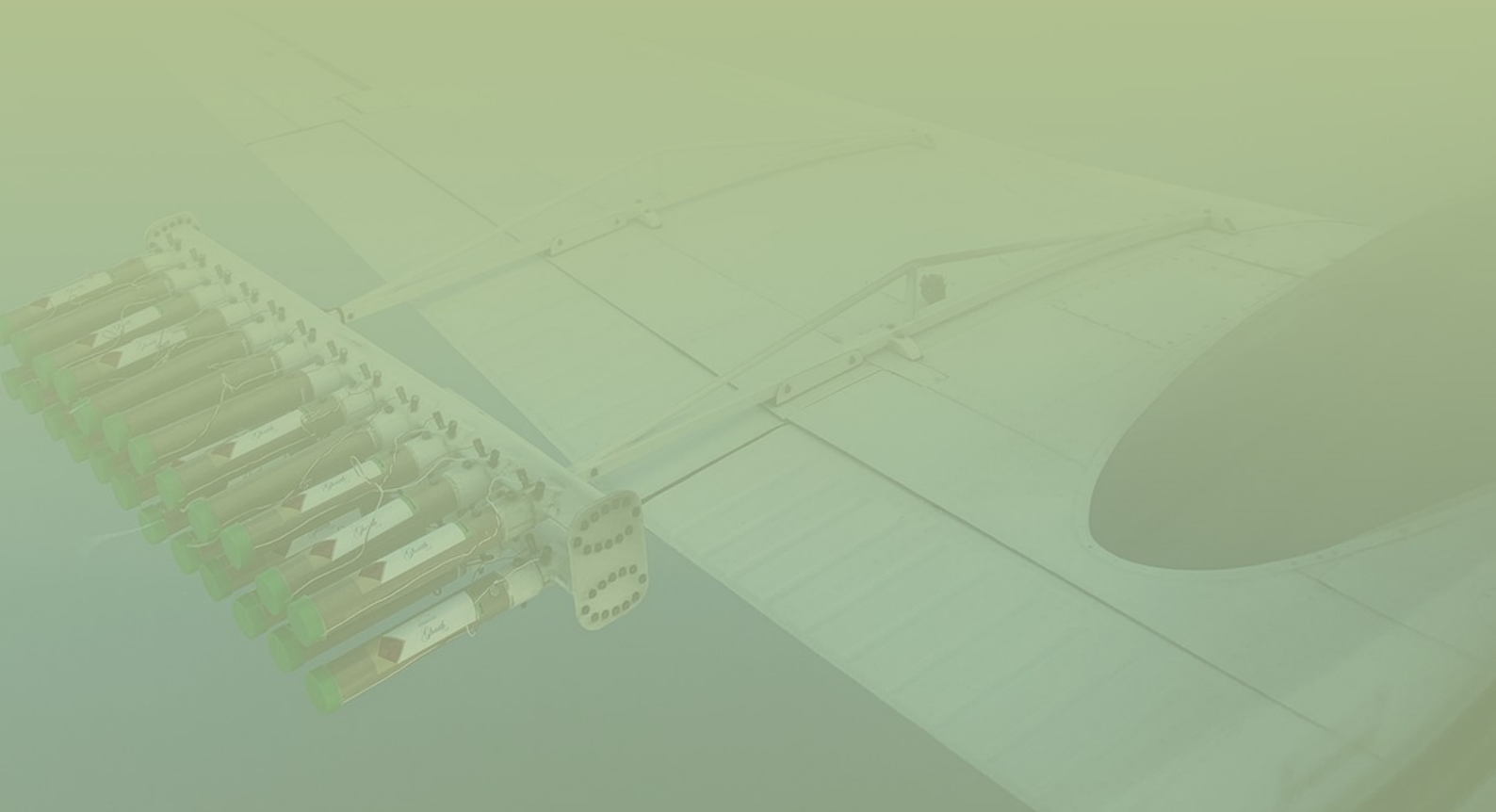
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Summary

- This Insight examines rainfall enhancement as a component of national water security, drawing on two decades of operational cloud seeding in the United Arab Emirates (UAE) and ten years of the UAE Research Program for Rain Enhancement Science (UAEREP), a grant programme managed by the National Center of Meteorology (NCM).
- It argues that rainfall enhancement is a low-cost complement to desalination and groundwater, not a substitute for them. On the cost of mission flights alone, seeded rainfall reaching the ground is estimated at USD 0.01 to 0.04 per cubic metre, against USD 0.31 reported for Dubai's Hassyan desalination plant; the comparison excludes capture and storage, and the effect of seeding on a whole season's rainfall remains uncertain.[1]
- It also presents the concept of targeted land-surface modification for rainfall enhancement, recently moving from conceptual models to field measurement: a large dark surface such as a solar park or plantation heats the air above it, which on suitable summer days can rise and form rain clouds downwind, linking water, energy, food and land use.
- It describes how UAEREP has funded 17 research projects led by institutions across ten countries, how their results have entered NCM operations, and how NCM has worked with Pakistan, Mauritania, Ethiopia and, since May 2026, Kazakhstan.
- With the UAE and Senegal co-hosting the UN Water Conference in December 2026, the Insight positions rainfall enhancement as an offer to water-stressed countries, provided it comes with the evaluation and governance standards that make it credible.
- Based on this analysis, the Insight recommends:
  - » Counting enhanced rainfall in the national water portfolio, with its uncertainty range, and pairing seeding with harvesting and aquifer recharge so that rainfall translates to stored water.
  - » Planning future solar parks and plantations as water and energy infrastructures once the RAINLAND project concludes in 2029.
  - » Proposing, through the World Meteorological Organization (WMO) and the 2026 UN Water Conference, a common framework for evaluating and reporting rainfall enhancement activities.
  - » Building a South-South cooperation track that formalises NCM's support to partner countries as a programme of training, joint operations and evaluation.
  - » Improving research transparency, including on downwind effects and the environmental fate of seeding materials, so that operational seeding is not confused with climate intervention research.

The Issue

As an arid country that receives less than 80 millimetres of rain in an average year, the United Arab Emirates (UAE) has built its water security on technology. Desalination and treated wastewater now supply more than half of the national water portfolio, and the Water Security Strategy 2036 aims to cut total demand by 21% and raise the reuse of treated water to 95%.[2,3] The country's water stress indicator under Sustainable Development Goal 6.4.2 stands at around 1,510%, meaning it withdraws roughly fifteen times more freshwater than nature renews.[2]

This approach has served the UAE well, but its sources have known limits. Desalination is energy-intensive, exposed to disruption at sea and produces brine, while groundwater is being drawn down faster than it is replenished.[2,4] Desalination, reuse and groundwater all treat, recycle or mine water that is already on the ground; none of them draws on the moisture that passes over the country in the atmosphere.

Hygroscopic cloud seeding releases salt particles at the base of a growing cloud so that droplets form and merge into rain sooner. The country first tried the technique in 1982, has flown an operational programme since 2002 and established the UAE Research Program for Rain Enhancement Science (UAEREP) in 2015 to advance research and development.[1,4] For policy makers the open questions are how much water cloud seeding adds, at what cost, and on what terms the capability can be shared.

The following sections examine yield and cost, the land-surface route to rainfall, the international work of UAEREP and the National Center of Meteorology (NCM), and the outlook for the 2026 UN Water Conference.

Rain in the Portfolio: What Two Decades of Operations Show

NCM's operational programme includes four Beechcraft King Air aircraft based at Al Ain. Roughly 300 to 400 cloud seeding flight missions are flown per year, targeting tall convective clouds that build over the Hajar Mountains on summer afternoons and larger systems in other seasons.[1,5] The flares burn natural salts, principally sodium or potassium chloride, and since 2021 have also carried a salt particle engineered at the nanoscale to attract water at lower humidity, developed and patented under a UAEREP grant and now manufactured locally in Abu Dhabi.[4]

In 2021, NCM published an evaluation that compared rain gauge records before and after the programme began. Using the NCM radar network, the study tracked and compared 65 seeded storms against 87 unseeded and found an average increase of about 23% in annual rainfall over the seeded target area. The seeded storms grew larger and lasted longer within 15 to 25 minutes.[6] The World Meteorological Organization's (WMO) peer review reported increases "from essentially zero to more than 20%" in randomised experiments on winter mountain clouds and judged the seasonal effect on convective clouds, the type seeded in the UAE, less conclusive.[7,8] The United States Government Accountability Office (GAO) reached the same conclusion in December 2024.[9]

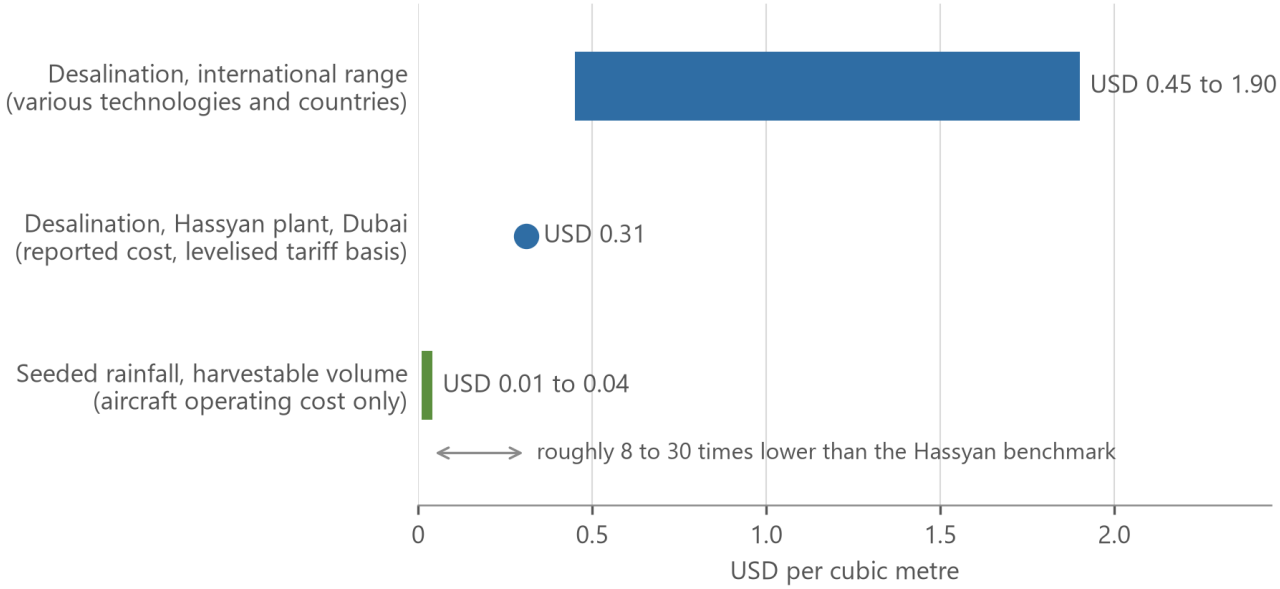
The evidence therefore sits at two scales: a single storm, where seeding measurably changes the cloud, and a season or river basin, where the increase cannot yet be stated with confidence because natural rainfall varies too much from year to year to isolate a modest signal. The WMO review notes that such seeding is undertaken as "a component of an overall approach to risk management of water resources, bearing in mind the substantial scientific uncertainties", which is the basis on which a diversified portfolio should count it.[8]

Even so, the economics are attractive. If seeding raised seasonal rainfall by 5 to 25%, the range Wehbe et al. (2023) drew from programmes reviewed by the WMO, and if half of the UAE's average annual rainfall of 6.7 billion cubic metres were targeted, then after losses to evaporation and soil the harvestable volume would be 84 to 419 million cubic metres a year. This is an order-of-magnitude exercise, not a measured yield. On the cost of seeding mission flights and resulting additional water, cost estimates range from USD 0.01 to 0.04 per cubic metre, compared with USD 0.31 reported for the Hassyan desalination plant in Dubai and USD 0.45 to 1.90 elsewhere (Figure 1).[1] The seeding figure excludes major aircraft maintenance, radar, forecasting and the dams and recharge

wells that turn rainfall into stored water. On that narrow measure seeding is far cheaper; whether the advantage survives a full life-cycle comparison has not yet been tested.

Enhanced rainfall yields usable water only when it is captured in wadis and dams and steered into underground stores. UAEREP's roadmap includes hydrological studies and calls for parallel investment in harvesting and aquifer recharge.[1,4] Counted this way, rainfall can be entered in the portfolio as a variable, weather-dependent source alongside desalination and reuse.

Figure 1. Indicative Unit Cost of Water by Source, USD per Cubic Metre
Source: Wehbe et al. (2023). The seeded rainfall figure covers aircraft flight hours only and excludes capture, storage and distribution; the Hassyan figure is a reported production cost on a levelised tariff basis.



Rain from the Land Surface: Solar Parks, Plantations and the Nexus

Aircraft can only seed clouds that exist, and on most summer days over the UAE interior there are none. UAEREP's first funding cycle in 2016 therefore funded a University of Hohenheim (Germany) project on whether the land surface itself could create them. The group's modelling, first for large plantations in Oman and then for dark or photovoltaic surfaces in the UAE, showed that a darker patch of desert heats the air above it, draws in the sea breeze and can lift moist air high enough to form cloud and rainfall downwind.[10,11] The UAE study simulated square dark surfaces of 10 to 50 kilometres a side on four summer days. Only surfaces of 20 kilometres or more produced rainfall consistently, around 570,000 cubic metres per rain day for a 20 by 20 km surface and 2.3 million for a 50 by 50 km surface, which on the authors' assumption of ten such days a year would supply between 31,000 and 125,000 people.[11]

The idea has been taken up elsewhere: European researchers writing in Global Change Biology in 2024 proposed "targeted rainfall enhancement" as an objective of forestation, citing the Hohenheim plantation work.[12] The follow-on sixth-cycle UAEREP project RAINLAND, led by Hohenheim with Khalifa University and under way since March 2026, will place laser-based lidar instruments around existing solar parks in Abu Dhabi and Dubai, subject to site access. The planned (2027) measurements will determine whether the solar parks already alter the local weather, then use fine-scale simulations to establish how large solar parks or artificial dunes would need to be, and where, to trigger rainfall reliably.[4,13] The project is expected to produce an implementation feasibility report for decision makers.

The land-surface route ties rainfall enhancement directly to the water-energy-food-environment nexus. A solar park sited where the sea breeze converges could generate electricity, trigger rainfall over the same landscape, recharge groundwater and power irrigation for drought-tolerant crops such as jojoba, which in turn cool the panels and improve the soil.[13] The UAE already builds solar parks covering tens of km^2, an order of magnitude below the modelled threshold, which is why RAINLAND is testing whether smaller or clustered surfaces have measurable effects. Until the field results are obtained, the sensible stance is to keep the option open in land and energy planning.

Other UAEREP projects feed the same operations: autonomous uncrewed aircraft from the University of Colorado, Boulder (USA) were transferred to NCM in 2023, machine-learning models from the Scripps Institution of Oceanography (USA) and the Hebrew University of Jerusalem (Israel) are being installed on NCM's supercomputer to identify clouds worth seeding and forecast rainfall up to six hours ahead, and exploratory research continues on electric charge, lasers and new ice-forming materials (Table 1).[4]

Table 1. Rainfall Enhancement Approaches Supported by UAEREP and Their Links to Water, Energy, Food and the Environment
Source: NCM and UAEREP (2025, 2026); stage descriptions are the programme's own assessments.

Approach	What it does	Stage reached	Intended nexus benefit
Salt-flare (hygroscopic) cloud seeding by aircraft	Salt flares released at cloud base start rain earlier in growing convective clouds	Operational since 2002; 300 to 400 missions per year	Water: recharge of wadis and aquifers
Nano-engineered seeding particles	Salt core with a titanium dioxide nano-shell attracts water at lower humidity than conventional hygroscopic flares	Used in operations since 2021; manufactured in Abu Dhabi	Water: designed to start droplet growth at lower humidity; environment: salt-based, locally produced
Autonomous uncrewed aircraft	Small drones measure clouds in real-time and deliver seeding material with precision (timing and location)	Demonstrated in the United States; transferred to NCM in 2023	Water: lower cost per mission once flown in UAE airspace
Artificial intelligence (AI) cloud targeting and evaluation	Machine learning on radar and satellite data selects seedable clouds and measures effects	Prototypes running on NCM's supercomputer; radar data upgrade under way	Water: evidence for every mission
Land-cover modification (solar parks, plantations)	Darker, warmer surfaces draw in the sea breeze and trigger convective cloud downwind	Modelling proof of concept at 20 km and above; field measurements from 2027 (RAINLAND)	Water, energy, food and land in one investment
Land-form modification (artificial dunes)	Engineered ridges lift moist air, as mountains do	Concept stage; assessed within RAINLAND to 2029	Water; land reclamation
Electric charge, lasers, artificial updrafts	Alternative ways to start droplet growth or lift air	Exploratory; field results inconclusive or laboratory only	Environment: charge and lasers disperse no seeding material; the jet-engine updraft trials burned fuel and injected aerosol

A Programme Built for Collaboration: UAEREP and NCM Abroad

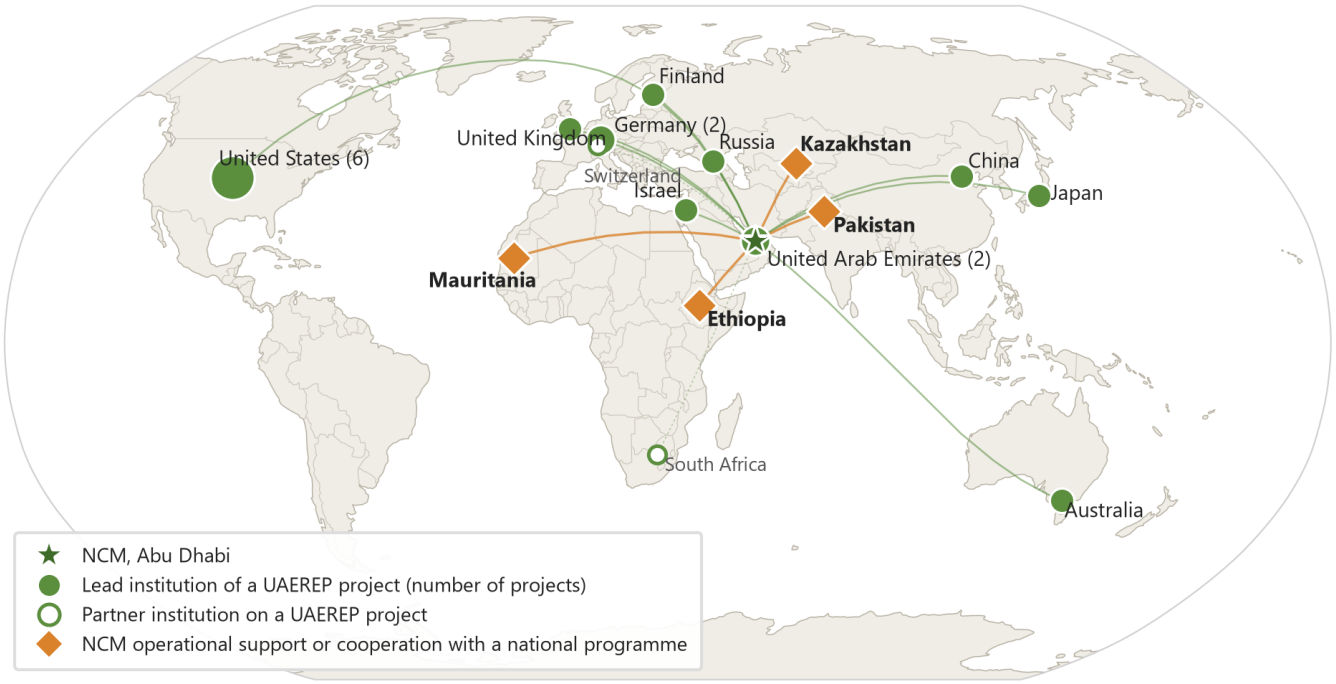
UAEREP was launched in 2015 under the patronage of His Highness Sheikh Mansour bin Zayed Al Nahyan, Vice President, Deputy Prime Minister and Chairman of the Presidential Court, as a Presidential Court initiative managed by NCM. It runs an open international competition every two years, with awards of up to USD 1.5 million over three years. Six cycles have funded 17 projects led by institutions in ten countries on four continents, with close to USD 25 million in grants as of January 2026; the sixth cycle alone drew 140 proposals from 48 countries.[4,14]

Awardees have produced more than 100 peer-reviewed articles and ten patents co-owned with NCM, and the programme's calls and events have engaged researchers from more than 80 countries.[4]

The programme's reach follows from its design: proposals are scored on capacity building in the UAE as well as on science, every project must show a route to operational use, and data are expected to be published.[15] The UAE, through NCM and UAEREP, funded the WMO's 2018 peer review, and the GAO's 2024 assessment cites the UAE programme and its published evaluation among its sources.[8,9] The International Rain Enhancement Forum (IREF), held for the seventh time in Abu Dhabi in January 2025, is now one of the field's largest international gatherings.[4]

NCM's operational support has also crossed borders. In December 2023, at the Punjab government's request, an NCM team flew two aircraft to Lahore and released 48 flares over ten areas of the city in Pakistan's first use of rainfall enhancement against winter smog, an air-quality demonstration rather than a water-supply operation.[16] In September 2024, NCM conducted Mauritania's first cloud seeding operation, over the Adrar region with Mauritanian counterparts.[17] NCM has also worked with Ethiopia, which launched its own programme in 2021.[18,19] The largest engagement began on 16 May 2026 in Kazakhstan's Turkistan region, with the national meteorological service Kazhydromet: UAE crews flew seeding missions over 911,000 hectares of farmland and trained Kazakh meteorologists, engineers and pilots, targeting 10 to 20% more rainfall in favourable conditions (Figure 2).[20,21,22]

Figure 2. UAEREP's International Research Network and NCM's Operational Partnerships, 2016–2026
Source: authors, from NCM and UAEREP records. Lead institutions are attributed to the country of the institution of record at award; operational support or cooperation as reported in 2023–2026.



Two features of this model matter for diplomacy: it is open to any institution in any country, and it exports evidence rather than equipment alone. A seeding flight without radar-guided missions and evaluation cannot provide a cost-benefit analysis for governments. UAEREP's investment in evaluation, from radar analysis to statistical methods that separate the effect of seeding from natural variation, fills the important gap of rigorous cost-benefit analyses for operational programmes.

The 2026 UN Water Conference: Making the Offer Credible

The UN Water Conference on 8 to 10 December 2026, co-hosted by the UAE and Senegal, is only the third such conference since 1977.[2,23] Its six dialogue themes, adopted in July 2025, include "Water for prosperity", which covers the water-energy-food nexus, "Water for cooperation" on transboundary waters, "Water in multilateral processes" and "Investments for water".[24,25] Around four billion people face severe water scarcity for at least part of the year,[26] and several of the most exposed countries already run or have trialled seeding: the GAO's list of 39 active countries includes Burkina Faso, Ethiopia, Mali, Niger and Senegal, the conference co-host.[9] Suitability depends strictly on local cloud climatology, so any cloud seeding programme planning requires a scientific assessment of seedable conditions.[8]

For cloud seeding programmes to be credible, three things need to be in place. First, the numbers must be calibrated. NCM's 2023 assessment describes its own yield figures as high-level estimates that need watershed-scale research, and the WMO and the GAO both stress that few estimates carry statistical confidence.[1,9] An entity that presents rainfall enhancement as a risk-management tool, with the uncertainty stated, will be more credible than one that presents it as a solution.

Second, there is almost no governance to point to. The GAO found "few international or domestic regulations" governing peaceful weather modification.[9] In its June 2025 statement on weather modification, the WMO notes that programmes now run in more than 50 countries, that it "neither promotes nor discourages the practice", and that downwind and environmental effects "need further investigation".[27] The Kazakh project illustrates the gap: by August, fears of "cloud theft" had been voiced in neighbouring Kyrgyzstan, including by a former prime minister, although Kazakhstan's meteorological service and independent scientists say the effects are local and short-lived.[20,28] As co-host and a long-standing contributor to the WMO's work on weather modification, the UAE is well placed to propose, through the WMO Expert Team on Weather Modification, a shared framework for evaluation, open reporting and advance notification of neighbouring meteorological services when seeding is planned near a shared border.

Third, the public has to be able to tell seeding apart from weather control. When heavy rain flooded Dubai on 16 April 2024, cloud seeding was blamed on social media almost immediately, although NCM had flown no seeding mission during the storm and its forecasters attributed the deluge to warm, humid Arabian Sea air meeting a cold air mass from the north-west.[29] Because UAEREP's own research agenda includes small-scale climate interventions such as land-cover change and, at the exploratory end, regional solar radiation studies, there is a further reason to publish what is funded and what is operational, so that seeding is not confused with climate intervention, which the WMO's 2025 statement treats separately.[4,27] Logging every seeding mission, as NCM currently does, and publishing the evaluations that follow would be the best defence.

Conclusion

The UAE's experience shows that rainfall enhancement belongs in a national water portfolio on three conditions: its cost is stated in full, its effect is measured every season, and the rainfall it produces is captured and stored. Under those conditions it adds water at low operating cost, and the land-surface route could in time turn solar parks and plantations into water infrastructure. UAEREP has built the evidence base that makes these claims testable, and NCM has begun to share the capability with partners abroad. The December 2026 UN Water Conference gives the UAE an occasion to turn that record into a standing offer, with the standards attached that other countries need to adopt it.

Policy Recommendations

Ahead of the UN Water Conference, the UAE could move rainfall enhancement from a national capability to a shared one. That will require action at home on accounting and planning, and abroad on standards and cooperation:

1. Counting enhanced rainfall in the national water portfolio. The UAE Ministry of Energy and Infrastructure (MOEI) may consider adding an annual reporting line under the Water Security Strategy 2036 on seeding operations, their evaluated effect with its uncertainty range and the recharge captured, and pairing NCM's operations with investment in harvesting and aquifer recharge.

2. Planning solar parks and plantations as water infrastructure. The MOEI and the utilities that develop the solar parks, Emirates Water and Electricity Company (EWEC) and Dubai Electricity and Water Authority (DEWA), could consider building the option of testing rainfall effects into siting and sizing decisions based on the UAEREP RAINLAND project results, with a kilometre-scale pilot demonstration to follow if the results justify it.

3. Proposing an international evaluation and reporting standard. Through the WMO Expert Team on Weather Modification and the conference dialogue on "Water in multilateral processes", the UAE could propose a common framework covering evaluation that compares seeded storms with similar unseeded ones, open data, environmental monitoring and advance notification of neighbouring states.

4. Building a South-South cooperation track. NCM's support to Pakistan, Mauritania, Ethiopia and Kazakhstan could be formalised as a programme of training, joint operations and evaluation, offered under the dialogues on "Water for cooperation" and "Investments for water", financed through existing development-cooperation instruments and judged on capacity built in the partner country, with priority for countries with suitable cloud climatology.

5. Keeping the science open. UAEREP's seventh cycle, which opens in December 2026, already lists cost-benefit analysis and the environmental effects of seeding agents among its research questions; the review committee could weight them in selection and add downwind effects, and NCM could add a published post-season evaluation to its mission announcements.

These steps would let the UAE arrive in December with a method it has objectively costed and evaluated, sharing the benefits with water-stressed countries and vulnerable communities.

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