

Water Security Risk – Part Three

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The Astonishing Transformation of Weather Modification: From Dream to Reality

Have you ever wondered what the world would look like if humans could, with the push of a button, make rain fall wherever they wanted? Perhaps this idea sounds more like science fiction than science, but the truth is that humanity has been trying to do exactly this for decades, sometimes with limited success and sometimes with controversial results. Today, more than fifty countries around the world are involved in this technology in one way or another, and the frontiers of knowledge in this field are expanding every day. However, what has transformed this field unprecedentedly in recent years is the entry of artificial intelligence and advanced technologies, a development that is turning cloud seeding from an experience-based art into a precise, data-driven science. This eventful journey, from early experiments to large-scale national projects, is a fascinating story that we will explore below.

Classical Methods: Cloud Seeding

The simplest and best-known method of weather modification is called cloud seeding, which has existed since the 1940s. In this method, substances such as silver iodide or dry ice (frozen carbon dioxide) are injected into cold clouds (below zero degrees Celsius) using aircraft, drones, rockets, or special cannons to create artificial ice crystals and induce rain or snow. Silver iodide has a crystalline structure similar to ice and, without the need to cool the environment, causes supercooled cloud droplets to freeze.

For warm clouds (above zero degrees Celsius), substances such as table salt (sodium chloride), potassium chloride, calcium chloride, or urea are used. By absorbing moisture, these substances create larger droplets and accelerate

rainfall. Methods for dispersing these materials include ground-based generators, airborne flares, and rockets carrying the seeding materials.

It should be noted that increasing rainfall is different from making rain. Cloud seeding is effective only when rain-capable clouds already exist. In other words, its role is like adding salt to food, not creating the food from nothing. Scientific evidence indicates that, at best, this method can increase precipitation by around 1 to 10 percent, and its effectiveness depends heavily on weather conditions and cloud type. The World Meteorological Organization (WMO, 2020) has also emphasized in its report that cloud seeding can be effective under specific conditions and with strict adherence to protocols.

Fog Dispersal

Another operational application of cloud seeding is the removal of fog at airports and on highways. In supercooled fog, artificial ice crystals are created using silver iodide or dry ice, causing the tiny fog droplets to be consumed and visibility to improve. This method is used at many airports around the world and is considered one of the most successful applications of cloud engineering.

Hail Reduction

By injecting seeding materials into hail-producing clouds, the number of ice nuclei is increased. This causes a larger number of smaller hailstones to form, which melt before reaching the ground. This method is widely used in countries such as China, the United States, and Russia, and experience in North Dakota has shown that seeding was effective in reducing hail in approximately 20.8 percent of cases.

The Artificial Intelligence Revolution in Weather Modification

Perhaps the most important development of the past decade in cloud engineering has been the introduction of artificial intelligence into this field. AI is no longer merely an auxiliary tool; it is becoming the brain behind cloud-seeding operations. But exactly what does AI do?

Precise Prediction of the Location and Timing of Seeding

The traditional challenge in cloud seeding is determining which cloud is suitable for seeding and at what time. For years, pilots and experts made

decisions based on experience and satellite imagery. Today, however, AI systems can simultaneously analyze satellite data, radar observations, weather models, and even historical data, enabling them to predict the location for seeding with unprecedented accuracy. In the United Arab Emirates, an AI system can predict a suitable location for seeding up to six hours in advance. This means that instead of experimental flights, operations can be carried out with a precise target.

Improving the Accuracy of Weather Models

The AI company Atmo uses deep-learning models trained on more than 60 years of climate data. It has developed weather models that are reportedly up to 100 times more accurate and 40,000 times faster than traditional supercomputers. This means that forecasting cloud conditions and identifying the best time for operations can be done with a speed and accuracy that was previously impossible.

Real-Time Assessment of Effectiveness

One of the biggest challenges of cloud seeding is answering the question: Was the rainfall that occurred the result of the operation, or was it a natural phenomenon? AI can analyze data from dual-polarization radar, which can distinguish among rain, hail, snow, ice, and even insects, and compare it with forecasting models to measure the effect of an operation in real time.

Reducing Costs and Unnecessary Flights

With more accurate forecasting, the number of seeding flights that fail to produce results can be significantly reduced. This means substantial savings in fuel, costs, and time.

In November 2025, the World Meteorological Organization (WMO) held its 11th Scientific Conference focusing on the role of AI in weather modification. At the conference, attended by more than 220 scientists, key topics included the use of AI and drones to support real-time decision-making in cloud seeding, and the field's transition from asking "Does weather modification work?" to asking "How can it be integrated into operational systems?"

New Technologies: From Drones to Lasers, Plasma, and Nanomaterials

The world of weather modification is rapidly evolving, and classical methods are giving way to more advanced technologies.

Cloud-Seeding Drones

Drones, with their high maneuverability, lower costs, and ability to fly in difficult conditions, have revolutionized cloud-seeding operations. The company Rainmaker has developed a drone weighing less than 25 kilograms that is capable of flying under severe icing conditions. These drones can operate in groups and coordinate with artificial intelligence. In March 2025, China conducted a large-scale cloud-seeding operation in northern China using a fleet of 30 aircraft and drones, which resulted in a 20 percent increase in rainfall in the target area.

Ultrashort Lasers

Scientists at the University of Geneva and research centers in the UAE are using laser pulses to create plasma channels in the air that act like microscopic lightning bolts and stimulate the process of rain formation. This method, which does not require chemical materials, is currently at the field-testing stage.

Sound Waves

This is a non-chemical and low-cost method that uses sound waves to influence the distribution of rainfall and is being applied in arid and semi-arid regions to improve water resources.

Plasma and Electric-Charge Seeding

Laboratory research has shown that atmospheric-pressure plasma can increase the formation of cloud condensation nuclei several times over. Drones equipped with electrical-discharge systems are also being tested in the UAE to deliver electrical charges into clouds and stimulate raindrop formation.

Nanomaterials

One of the major concerns surrounding cloud seeding is the environmental impact of silver iodide. In 2025, researchers developed a biodegradable nanocomposite that is activated using microwaves and lasers and can produce up to **1.18×10^{14} particles of active seeding material per gram.**

Professor Linda Zou of Victoria University in Australia, with **\$1.5 million in funding from a UAE research program**, is also developing advanced nanostructured materials specifically designed to form ice crystals in clouds. These materials could provide more effective and environmentally compatible alternatives to silver iodide.

Military Applications: When Weather Becomes a Weapon

It may seem unbelievable, but the history of weather modification for military purposes is almost as old as the technology itself. Operation Popeye during the Vietnam War is considered the most prominent and well-documented military project in this field. Between 1967 and 1972, the U.S. Air Force conducted more than 26,000 flights and deployed 474 million seeding bombs, targeting clouds over the Ho Chi Minh Trail in an attempt to extend the monsoon season by up to 45 days and turn the enemy's supply routes into impassable swamps. Historical documents show that the project was carried out with the support of the highest-ranking officials, including President Lyndon Johnson and Secretary of State Henry Kissinger.

In addition, the U.S. Navy's Project Stormfury (1962–1983) sought to weaken tropical storms, although later research showed that the method had limited success because of the large amount of natural ice already present inside storms. Britain's Project Cumulus in the 1950s also investigated the effect of cloud seeding on increasing rainfall for military applications.

These actions and concerns over weather warfare led to the adoption of the **Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD)** in 1976. The treaty prohibits hostile use of environmental modification techniques that have widespread, long-lasting, or severe effects. The convention explicitly includes modifications of weather patterns—including clouds, precipitation, and storms—within its scope of prohibition. According to recent legal research, the convention may have broader potential applications than previously assumed and could protect the environment against deliberate harm by states, particularly during armed conflicts.

Threats to Iran's Water Infrastructure: From the Iran-Iraq War to Recent Wars

During the Iran-Iraq War (1980–1988), water infrastructure in various parts of the country suffered significant damage. In Khuzestan Province, border cities including Abadan, Khorramshahr, and Dezful witnessed extensive destruction of water-supply networks. In Lorestan and Kermanshah provinces, rural and urban water-supply networks were also significantly damaged.

However, during the more recent wars (2025–2026), the threats have reached an unprecedented level. From late February 2026, joint U.S.-Israeli air and cyberattacks systematically targeted dozens of water-transfer and water-treatment facilities. In June 2025, Israeli fighter jets bombed a major water-transfer pipeline in Tehran, causing water to flood the streets. A desalination plant on Qeshm Island was also disrupted, and Iran formally complained to UNESCO. At the same time, widespread cyberattacks affected more than 80,000 sites, while Israel, in response to Iranian cyberattacks, launched a counterattack against Shahid Rajaei Port. On March 22, 2026, Iran threatened that if its energy facilities were attacked, it would attack desalination plants across the Persian Gulf region. These events indicate that threats to water infrastructure through military means have become a new and alarming dimension of regional conflicts aimed at reducing civilian resilience, in which water facilities are no longer a secondary target but one of the principal objectives on the battlefield.

Successful Projects Around the World: From China to the UAE

Over the decades, numerous projects have been implemented in different parts of the world with varying degrees of success, some of which have become notable models:

China has the world's largest weather-modification program. In 2023, a fleet of drones in Xinjiang used only 1 kilogram of silver iodide to increase rainfall by more than 4% over a single day across an area of 8,000 square kilometers, producing more than 70,000 cubic meters of additional rain. In 2024, Xinjiang Province conducted 123 flights and nearly 5,000 ground operations, achieving an increase of 14.41 billion cubic meters in precipitation. In March 2025, China

also conducted a spring rainmaking operation in northern China using a fleet of 30 aircraft and drones. During the 2008 Beijing Olympics, successful rain-dispersal operations prevented rainfall during the opening ceremony.

The United Arab Emirates, with its extensive cloud-seeding program since the early 2000s, has become one of the most successful examples of increasing rainfall in arid regions. The program conducts hundreds of seeding flights annually, and reports indicate a 10–30% increase in rainfall in some areas. In 2025, the UAE launched three new research projects, each receiving \$1.5 million in funding, during the fourth cycle of its Rain Enhancement Research Program, all focused on artificial intelligence. It has also begun testing a high-powered laser system designed to generate rain under dry conditions.

The United States has a long and diverse history in this field. States such as Colorado, Utah, and California have used cloud seeding for decades to increase snowfall in mountainous areas. Rainmaker and Atmo also formed a strategic partnership in 2025 to develop a high-precision weather-modification platform.

Saudi Arabia has experienced a remarkable increase in rainfall. A study in the Al-Baha region found that seeding operations in August increased the number of rainy days from 1.87 days to 25 days and raised the volume of precipitation to 585%.

In Indonesia (2019), cloud-seeding operations in Jakarta reduced rainfall intensity by 38%. Thailand has continued its Royal Rainmaking Project since the 1960s. Japan has established an ambitious Moonshot Goals project that even includes the control of typhoons.

India also conducted its first drone-based cloud-seeding experiment in Jaipur in 2025 and used the Hydro Trace AI platform to identify suitable clouds.

However, the experience of countries such as Israel, which suspended its program in 2021 because of a lack of significant success, demonstrates that this technology is not a panacea and that its success depends heavily on atmospheric and regional conditions.

Iran's Critical Water Situation and Lessons from Countries with Similar Climates

With average annual precipitation of around 250 millimeters, Iran is considered one of the driest countries in the world. This amount is approximately one-third of the global average (Iran Meteorological Organization, 2023). According to a World Bank report (2023), Iran is among the 36 countries experiencing high water stress. According to Iran's Ministry of Energy, water consumption in Iran is approximately 2.5 billion cubic meters per day, more than 92% of which is used in agriculture. Irrigation efficiency in Iran is around 35–40%, while in developed countries it exceeds 70% (FAO, 2022). Iran's average temperature has increased by approximately 1.5°C in recent decades.

Iran also took important steps in 2025 in the field of cloud-seeding drones. The Ministry of Energy announced the start of construction of specialized cloud-seeding drones capable of increasing precipitation by 15–20%. These drones, considered innovative at the global level, operate in coordination with aircraft and ground equipment. Four operational areas for cloud seeding have also been designated for the current week.

Meanwhile, countries with climates similar to Iran have accumulated valuable experience in water management. The United Arab Emirates, with average annual precipitation of less than 100 millimeters, has made significant investments in water desalination and recycling technologies. Saudi Arabia, through investment in water technologies, has partially secured its food security (FAO, 2022). Israel is scientifically one of the world's leaders in water management; irrigation efficiency in the country exceeds 90%, and approximately 90% of wastewater is treated and recycled (World Bank, 2023).

Indigenous Water Management Technologies in Iran

In recent years, Iran has taken important steps in developing technologies related to water management. According to a report by the Iranian Space Agency, the Rasad satellites (2011), with high-resolution imaging capabilities, Payam (2018) for communications, and Doosti (2019), developed in cooperation with China, can be used to monitor changes in the water levels of lakes, monitor soil moisture, and assess vegetation cover. Iran also has more than 1,500 meteorological stations, including synoptic, climatological, rain-gauge, and climate stations. Flood and drought warning systems, including weather radar networks, river monitoring systems, drought monitoring, and flood warning systems, have also been developed in Iran.

What Will the Future Look Like?

Given the remarkable advances, the future of weather modification is both exciting and alarming. Governments and research centers are examining local and regional technologies.

Full automation of operations: Combining artificial intelligence, autonomous drones, and real-time assessment systems could lead to fully automated cloud-seeding operations. The 11th WMO Conference in November 2025 explicitly addressed semi-autonomous activities in weather modification.

Swarm drones: Researchers are developing fleets of autonomous drones that operate collectively and in coordination. This approach addresses the payload limitations of individual drones and dramatically increases operational precision.

AI-based climate engineering: Beyond cloud seeding, researchers are using reinforcement learning to control the distribution of particle concentrations in the stratosphere in order to reduce global warming. Elon Musk also proposed a

controversial idea in 2025 involving the use of AI-equipped satellites to reduce solar radiation and combat global warming.

Typhoon control: Through its Moonshot Goals project, Japan is seeking to control typhoons, while scientists are examining theoretical methods such as “weather jujitsu,” in which small, timely interventions in the atmosphere could alter the paths of storms.

Geoengineering and security risks: Climate-engineering technologies such as stratospheric aerosol injection (SAI), although technically feasible and accessible to many countries, have almost no global governance framework regulating such activities. This creates incentives for unilateral action that could lead to armed conflicts. Researchers warn that countries may perceive unilateral SAI actions as a threat to national security. Non-ideal scenarios, such as competitive or malicious deployments, could also produce unpredictable political and cultural consequences. At the international level, existing treaties such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement essentially say nothing about SRM (Solar Radiation Management), and governance in this area remains highly fragmented and incomplete.

From a military and security perspective, experts warn that as these technologies expand, we may witness a form of climate Cold War. The United Nations is attempting to prevent such scenarios by developing clearer rules, but existing legal gaps have created significant challenges for these efforts.

A Look at Conspiracy Theories: HAARP and Climate Weapons

Alongside scientific realities, the world of conspiracy theories surrounding weather modification is highly active. The High-frequency Active Auroral Research Program (HAARP) in Alaska, a research facility for studying the ionosphere (the upper layer of the atmosphere), has continually been the

target of such theories. Many believe that HAARP can cause earthquakes, heat waves, or floods. However, scientists have repeatedly stated that there is no known mechanism through which HAARP could influence atmospheric phenomena. Weather forms in the troposphere (0–15 kilometers), while HAARP affects the ionosphere (60–500 kilometers), and these two layers are completely separated. HAARP's output power is approximately 3.6 megawatts, which is even less than the power of a large wind turbine (5 megawatts).

Another widely used concept in conspiracy theories is “chemtrail spraying,” which claims that aircraft condensation trails contain chemical substances. This claim has also been completely rejected by scientists. Contrails are a completely natural phenomenon caused by water vapor emitted from aircraft engines interacting with cold air at high altitudes, and they consist of ice crystals rather than chemical substances.

Legal and Ethical Framework: The Boundaries of Use

One of the most important aspects of artificial weather modification is its legal and ethical framework. The Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD, 1976) is the most important international document in this field and prohibits the hostile use of environmental modification techniques. The United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement are also indirectly related to this issue. Iran is a member of the UNFCCC and ratified the Paris Agreement in 2016.

In 2026, the United Nations General Assembly adopted a resolution stating that failure by countries to fulfill their climate commitments could constitute an internationally wrongful act. The resolution, adopted by 141 votes in favor and 8 against, could provide a legal basis for pursuing countries whose weather-related actions harm other countries.

Within Iran, Article 50 of the Constitution considers environmental protection a duty of the government, while laws such as the Fair Water Distribution Law (1982) and the Law on the Protection and Utilization of Water Resources (2013) establish legal frameworks for water management.

However, serious gaps remain in the international framework. The distinction between peaceful and hostile applications has not been clearly defined. In addition, the armed forces of countries are exempt from reporting their carbon emissions, which itself constitutes a major gap in the climate field, with military activities accounting for approximately 5–6 percent of total global emissions. Many key countries are also not parties to the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD).

Smart Water Governance: The Architecture of National Will, from Data to Life

The architecture of a smart water and climate Iran is not merely the construction of a technological skeleton made up of sensors and satellites; it is a new philosophy of governance that breathes the spirit of collective will into this body. This vision marks the end of an era of centralized decision-making and the beginning of an age of polycentric governance: a dynamic national orchestra in which the government, universities, the private sector, and local communities all play the future of water using a common language and shared score—the same precise and transparent data.

This model, inspired by integrated management in Israel, absolute self-sufficiency in Singapore, and local water boards in the Netherlands, returns power from the center to the people themselves. In this ecosystem, information is no longer an archived report but an economic engine that transforms a drought warning into an opportunity for the smart farmer.

Thus, adding this spirit of participatory governance to the technological skeleton transforms it into a living, intelligent, adaptable, and wealth-

generating organism capable of safeguarding the vital pulse of this land for generations to come.

Final Conclusion: From Science to Policy

Artificial weather modification is no longer a dream or a cinematic threat; it is a scientific reality that is rapidly advancing. Today's technologies, such as cloud seeding, have limited but real effectiveness, and successful projects in China, the UAE, and the United States have shown that this technology can serve as a valuable complementary tool for managing water resources and reducing natural disasters.

However, the most important transformation in this field is the entry of artificial intelligence. By more accurately predicting the location and timing of seeding, assessing the effectiveness of operations in real time, and reducing unnecessary costs, AI is becoming the brain of cloud-seeding operations.

New technologies such as autonomous drones (with swarm-flight capabilities), nanomaterials (environmentally friendly alternatives to silver iodide), ultrashort lasers, plasma, and dual-polarization radars, all assisted by artificial intelligence, have brought the precision and efficiency of operations to an unprecedented level. Iran has also taken steps in this direction by producing cloud-seeding drones and targeting a 15–20 percent increase in precipitation.

Iran is grappling with a deep water crisis and climate change. With average annual precipitation of 250 millimeters, low irrigation efficiency (35–40 percent), and a 1.5-degree increase in temperature, the country is among the 36 countries facing high water stress. The experience of countries with similar climates shows that investment in modern water-management technologies, improving irrigation efficiency, and developing water-recycling systems can provide solutions.

But more important than technical capabilities are the ethical, legal, and security questions before us: Who decides to alter the weather? How can we prevent the military misuse of this technology? Will weather modification benefit all humanity, or will it come at the expense of harming others?

The existing legal framework, from the ENMOD Convention to the 2026 United Nations resolution, represents steps in the right direction, but serious gaps—such as the ambiguous definition of hostile use and the non-membership of many countries in key treaties—remain major challenges. In a world where climate change has become one of humanity's greatest challenges, the ability to alter the weather can be both lifesaving and destructive, and it is up to us to decide how this power should be used.

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