INTERNATIONAL JOURNAL OF SOCIAL SCIENCE, MANAGEMENT, PEACE AND CONFLICT RESEARCH (IJSMPCR)
Journal homepage: https://ijsmpcr.com/

Cloud seeding technology and its potential influence on food security in Nigeria

By
DUKE-ABIOLA Queen Akasoba *mni*., ZAMANI Andrew. E. Prof., & ONIBIYO Ezekiel
[1&2]Institute of Governance and Development Study, Nasarawa State University Keffi, Nigeria
[3]APUDI Institute for Peace Studies and Social Rehabilitation, Abuja

International Journal of Social Science, Management, Peace and Conflict Research, 10(01), 125-138
Publication history: Received on October 5; Revised on October 15, 2025; Accepted on October 19, 2025

Abstract

There is no gainsaying that Nigeria lags behind on Cloud Seeding technology despite her exposure to extensive land aridity in her northern region. Cloud seeding technology which could facilitate water augmentation thus leading to food security is grossly missing in Nigeria's climate change mitigation strategies even as same technology could be engaged as counterterrorism measure on profiled terror cells. This study engaged Social-Technical Systems Theory to explain Cloud seeding technology and its potential influence on food security in Nigeria. An exploratory research design was employed, utilizing secondary data sourced from journal publications, official reports, internet databases, and conference proceedings. The analysis explored literature on cloud seeding, national security, climate change, and food security, providing a comprehensive understanding of the subject. Findings from the study revealed that cloud seeding in Nigeria is impeded by significant challenges, including a lack of awareness among stakeholders, inadequate infrastructure, absence of government policies, limited funding, weak government-private sector collaboration, insufficient technical expertise, and environmental risks. These challenges pose a threat to national security, particularly in addressing water scarcity and enhancing agricultural productivity. Despite these barriers, evidence from literature affirms that cloud seeding offers immense potential in improving food security by reducing drought-related losses, enhancing crop yields, and addressing water stress as a major cause of crop failure. The study concludes that addressing the challenges of cloud seeding is critical for its adoption as a viable strategy for improving food security and climate change resilience in Nigeria. The study recommended that the Federal government and the North East Development Commission must deliberately foster research and innovation in cloud seeding techniques. Additionally, the study recommended institutionalizing cloud seeding within Nigeria's water resource management policies and promoting government-private sector partnerships, vital for maximizing its benefits.

Keywords: Cloud Seeding, Food Security, National Security, Social-Technical Systems Theory

Introduction

Weather modification, particularly cloud seeding, has emerged as a potential global tool to address environmental challenges whose interconnectedness with national security has been long established in literature. The United Nations by the 1979 Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD), assented by 78 countries, frown against weather warfare and climate modification technologies (Smit, 2015). The United States, China, and Israel have used cloud seeding to increase rainfall, augment water resources, and mitigate drought. This technology has significant implications for national security, as climate-induced stress on resources such as food security, environmental degradation, and water scarcity can fuel social unrest, conflict, and economic instability (Fleming, 2010).

* Corresponding author: **DUKE-ABIOLA Queen Akasoba *mni***
Department of Security and Strategic Studies, Nasarawa State University, Keffi, Nigeria.

In the context of food security, cloud seeding can play a crucial role in regions where agricultural productivity is hampered by erratic rainfall. In China, cloud seeding has been employed to increase rainfall over agricultural regions, helping to sustain crop yields and prevent food shortages (Zhou & Wang, 2019). By ensuring a more reliable water supply for irrigation, cloud seeding can support national security by stabilizing food systems and reducing vulnerability to food crises. In Nigeria, where agriculture forms the backbone of the economy, particularly in rural areas, ensuring consistent rainfall through cloud seeding could help safeguard food security and prevent conflicts that may arise from food scarcity (Onuigbo, 2018).

Water augmentation is another critical area where cloud seeding can influence national security. Many countries, particularly in arid and semi-arid regions, are increasingly relying on cloud seeding to replenish water reservoirs and sustain water supply for domestic and industrial use. The United Arab Emirates, for example, has been implementing cloud seeding to augment its limited freshwater resources (Khalid, 2020). Water scarcity in Nigeria, especially in the northern regions, has been a source of tension and conflict between communities. Implementing cloud seeding could alleviate water shortages, contributing to national security by reducing competition over scarce water resources and fostering peaceful coexistence among communities.

In Africa, Morocco's Al-Ghaith cloud seeding program dated back top 1984, with an allocated fund of €10 million since 2023 to boost its cloud seeding program in a bid to generate artificial rain and alleviate the structural drought(Faouzi, 2024). Burkina Faso used light aircraft to seed clouds in 1998, its positive experience persuaded the Inter State Committee Against Drought in the Sahel (CILSS) heads of state to consider the technology to enhance rainfall. Burkina Faso, Mali, and Niger also had their cloud seeding experience in 2000s (The Humanitarian, 2004).

The drying up of the Lake Chad Basin further amplified precipitation variability as a fallout of climate change. This further trigger Nigeria's insecurity as influx of terrorism, banditry, cattle rustling, transhumance movement, farmers-herders conflict, and food insecurity became the order of the day. This development further impacted and make unreliable both the North East and Northwest regions of Nigeria. This trajectory is not unconnected with the fragile balance between the groundwater and atmospheric moisture content which demands a sustainable future. Provenly, cloud seeding could address the burning issues of grazing, ranching, and deaccelerate terrorism in the Northeast and Northwest part of Nigeria.

The government of Sub-Saharan Countries must be seen deliberate in exploring different innovative approaches to tackle the scarcity of water in arid and semi-arid regions of the country as it is a source of tension and insecurity. Such intentional efforts will be guided by precipitation enhancement through weather modification technology. There is no gainsaying that there should be policy supports to engage the usage of unmanned aerial vehicle (UAV) actualise cloud seeding (Jung, 2022). Cloud seeding experiments with aircraft by United States and Thailand are conducting to increase long-term precipitation; suggested an increase in annual precipitation through cloud seeding (Rauber, 2019).

Statement of the Problem

The issue of national security in Nigeria is deeply intertwined with various environmental and socio-economic challenges. Among these, food and water security, degradable farmland, tension from transhumance movement, farmers herders conflict due to scarcity of resource, and all which are critical pillars, which are increasingly threatened by unpredictable weather patterns. Cloud seeding, a form of weather modification, has the potential to address some of these challenges by augmenting rainfall and improving resource availability.

Furthermore, the challenges of technical know-how and infrastructural fragility pose significant barriers to the successful implementation of cloud seeding in Nigeria. Despite its potential benefits, the country is yet to fully embrace cloud seeding technology due to the lack of skilled personnel, adequate facilities, and the requisite technology. These constraints not only hinder the adoption of cloud seeding but also undermine efforts to strengthen national security through innovative solutions to climate-related issues. Without a clear strategy and investment in weather modification, Nigeria's ability to mitigate the impact of environmental stresses on its food and water resources remains limited.

On Cloud seeding challenges; Anuar et al. (2024) in a Malaysia study examined cloud seeding potential areas using emote sensing; Ćurić and Janc (2014) in a Serbia Studies focused on danger of cloud seeding deposited chemical and its consequences. Essien (2023) zeroed on cloud seeding techniques for precipitation enhancement in a cross countries study; Parkes et al. (2015) investigated crop failure rates in a geoengineered climate in regions of China and West Africa. Wondie (2023) attention was on the nexus between technology for rain enhancement in Ethiopia. Jung et al. (2022) emphasised usage of unmanned aerial vehicle for cloud seeding in Korea. While Simon (2022) interrogated in cross country studies, extent to which cloud seeding laws can be used as a basis for governing regional solar radiation management activities.

To the extent of literature review, there exist an apparent gap in literature on Cloud seeding and National security in Nigeria, hence the need for this capstone study. It is this gap in literature that this study fill using unique constructs of Cloud Seeding and National Security, Cloud Seeding implementation constraints, Cloud Seeding and Food Security, Cloud Seeding and Water Augmentation, and Cloud Seeding and Policy frameworks in Nigeria. By examining these dimensions, this research aims to provide insights into how cloud seeding can contribute to a more secure and resilient Nigeria in the face of growing environmental uncertainties.

Objectives of the Study

The main objective of the study investigates Cloud seeding technology and its potential influence on food security in Nigeria. While specific objectives;

i. Examine challenges affecting cloud seeding in Nigeria.

ii. Evaluate influence of cloud seeding on food security in Nigeria.

Literature Review

Conceptual Framework

Concept of Cloud Seeding

The practice is a type of weather modification process whereby small planes fly through clouds burning salt flares which can increase precipitation to help make it rain. Cloud seeding is an established technology, developed after World War II to modify precipitation patterns to enhance rain and snow, or suppress hail. It is used as a long-term water management strategy to increase freshwater resources in key locations for water, food, and energy security (Simon, 2022).

Weather modification is a technology in which cloud seeding materials artificially cause cloud condensation and precipitation development in areas of the atmosphere with insufficient cloud condensation or ice nuclei. Weather modification techniques originated from the discovery that spraying artificial ice nuclei into supercooled clouds can increase the number concentration of ice crystals. The usual objective is to increase rain or snow, either for its own sake or to prevent precipitation from occurring in days afterward. Cloud seeding is done only when temperatures within the clouds are between 19 and minus-4 degrees Fahrenheit. This is the range at which silver iodide does its best work, as demonstrated by decades of research.

The goal of cloud seeding is to alter the natural development of the cloud to enhance precipitation, suppress hail, dissipate fog, or reduce lightning. Tata firms also took stabs at cloud seeding in the Western Ghats region in 1951 using ground-based silver iodide generators. The Rain and Cloud Physics Research (RCPR) unit of Indian Institute of Tropical Meteorology (IITM) in Pune carried out randomized warm cloud modification experiments through salt seeding during 1957-1966 in north India. Over the next three decades, India experimented in this direction in Maharashtra, Karnataka and Uttar Pradesh (Ghosh, 2019).

Chemical Charges

This is undertaken by dispersing substances into the air that serve as cloud condensation or ice nuclei. Common agents for chemical charges include silver iodide, potassium iodide, and dry ice, with hygroscopic materials like table salt gaining popularity due to their ability to attract moisture. This is the first experimented method which is still largely popular in achieving cloud seeding. Techniques vary from static seeding, which encourages ice particle formation in supercooled clouds to increase precipitation, to dynamic seeding, designed to enhance convective cloud development through the release of latent heat.

According to National Center for Biotechnology Information (2024), the most common chemicals used for cloud seeding include silver iodide, potassium iodide and dry ice (solid carbon dioxide). Liquid propane, which expands into a gas, has also been used. It can produce ice crystals at higher temperatures than silver iodide. After promising research, the use of hygroscopic materials, such as table salt, is becoming more popular (Hill & Ming, 2012)

A 10% increment of precipitation through cloud seeding can sustain an additional 150 000 households throughout an entire year (Abdallah & Evan, 2020). However, the lowest cost estimates published would be in the range of $27 to $53 per acre-foot (4000 m2) to produce additional precipitation (Larson, 2016). In 2016, Jeff Tilley, director of weather modification at the Desert Research Institute in Reno, claimed that new technology and research have produced reliable results that make cloud seeding a dependable and affordable water supply practice for many regions

The Dubai Experience of Cloud Seeding

The UAE, located in one of the hottest and driest regions on Earth, has been leading the effort to seed clouds and increase precipitation. National Centre for Meteorology, the UAE's meteorology agency, flew six or seven cloud seeding flights before the rain. More than 14cm (5.6 inches) of rain soaked the United Arab Emirates (UAE) city after the exercise. The result was the heaviest rainfall there since records began in 1949. The UAE does have an operational cloud seeding programme to enhance the rainfall in this arid part of the world, however, there is no technology in existence that can create or even severely modify this kind of rainfall event (Ambaum, 2023). The effectiveness of cloud seeding in augmenting precipitation levels, with a focus on silver iodide as a seeding agent advance the understanding of cloud seeding mechanisms within the broader context of weather modification. The Mesoscale convective systems (MCSs) are what we get when lots of individual thunderstorms amalgamate to form a single large high-level cloud shield, typically hundreds of kilometres across, together with a large region of heavy rainfall (Ghosh, 2019).

National Security

The traditional notion of national security is broaden to include non-military threats, such as food insecurity, water scarcity, and environmental risks (UNDP, 1994). In this context of cloud seeding, national security focuses on how environmental interventions directly impact individual and community well-being and national interest. By increasing water availability through cloud seeding, the technology can help combat droughts, secure agricultural yields, and thereby enhance food security. This is especially relevant in countries facing aridity, water stress or in regions where agriculture is vital to the economy and people's livelihoods. Policies aimed at ensuring food and water security align with both national security and the human security paradigm by prioritizing the protection of citizens from environmental threats (Sachs, 2012).

Food Security

A 2016 classified ad placed by Los Angeles County's Department of Public Works in the Pasadena Star News sparked claims that widespread weather modification was being confirmed. The department followed up with a clarification that it was only describing cloud seeding, used as an anti-drought measure intermittently for more than half a century in Los Angeles (LaCapria, 2016).

The Modesto and Turlock irrigation districts have seeded clouds over their Tuolumne River watershed, such that parts of the 257,314-acre burn area have a moderate to severe risk of soil erosion into streams and reservoirs during major storms (Weiser, 2014). Cloud seeding was rejected in Australia on environmental grounds because of concerns about the pygmy possum. The claims of negative environmental impact are disputed by peer-reviewed research (International Weather Modification Association, 2009)

Water Augmentation

Abundant rainfall in places unaccustomed to such conditions could lead to flooding, soil erosion, and deterioration. As cloud seeding might disrupt the atmosphere's relative humidity, potentially causing droughts in unexpected locations, intense downpours, increase the frequency of extreme weather events like storms, lightning, hailstorms, and tornadoes. The Spanish media raises concern over the possibility of geopolitical conflicts arising between affected states, such as Spain and Morocco, due to one country's decision to alter environmental conditions (Faouzi, 2024).

Hydro Tasmania began experimenting with cloud-seeding over lake catchments in central Tasmania in the early 1960s in order to determine if their electricity-producing dams could be kept at high water levels through cloud seeding. Tasmania proved to be one place where cloud seeding was highly effective. Various trials were undertaken between 1964 and 2005, and again between 2009 and 2016, but none have taken place since then. Hydro Tasmania also undertook soil and water survey samples and found negligible trace elements of the materials used for cloud seeding (such as silver iodine), and determined it did not have a detrimental effect on the environment.

Empirical Review

Cloud Seeding cchallenges and National security

Anuar et al. (2024) examined cloud seeding potential areas from remote sensing of low-level cloud due to location and temporal factors in Malaysia. Nowadays, low-level clouds' location can be detected using satellite remote sensing, to determine the potential areas for cloud seeding operations with remotely sensed low-level cloud distribution. The study elicited potential areas from the low-level cloud distribution of Terra

Moderate Resolution Imaging Spectroradiometer (MODIS) with cloud masking method and single reflective band and mapped with Geographic Information System (GIS) overlay analysis. Results that emanated from the study revealed that the locations were coincidentally used in previous cloud seeding operations which were above the 0.14 threshold. Thus, the potential areas based on low-level clouds for cloud seeding operations can be detected and mapped using Remote Sensing satellite images. The approach can potentially be utilised by related agencies to identify the appropriate areas for cloud seeding operations practically.

Ćurić and Janc (2014) investigated influence of tendencies for the amounts of chemical material used for cloud seeding for more than half a century and cover planetary scales in central and western Serbia. Findings from the study submitted that these cloud seeding activities lead to deposited chemical materials (seeding agents) at the ground level during precipitation, with high tendencies of increased amounts of seeding agent deposits to be a serious problem due to various negative effects on the human environment. The study also opine that the annual seeding agent amounts show a slow decreasing trend because fewer seedings were performed during the last decade of the last century, which was due to economic reasons. Study was done in Serbia with focus on challenges ahead from cloud seeding experiments while this study also engaged policy frameworks for cloud seeding in Nigeria.

Cloud seeding and food Security

Essien (2023) leveraged on Utilizing Social-Technical Systems Theory to investigate cloud seeding techniques for precipitation enhancement drawing from diverse geographical contexts, including the United States, Canada, Europe, and African countries. The study interrogated the varying patterns of precipitation and the potential for cloud seeding to address water scarcity challenges. Findings from the study opine that that silver iodide significantly increased precipitation in targeted areas, particularly during specific cloud types and favorable meteorological conditions. The result from a cost-benefit analysis reveals the economic viability of cloud seeding, with benefits such as increased agricultural productivity and reduced drought-related losses outweighing implementation costs. There is the need for Nigeria dataset driven study, hence the need for this study.

Parkes et al. (2015) investigated crop failure rates in a geoengineered climate on the number of crop failures in two regions, Northeastern China and West Africa. Climate change associated with a doubling of atmospheric carbon dioxide increases the number of crop failures in Northeastern China while reducing the number of crop failures in West Africa. In both regions marine cloud brightening is likely to reduce the number crop failures, although it is more effective at reducing mild crop failure than severe crop failure. Results from the study showed that water stress, rather than heat stress, is the main cause of crop failure in current, future and geoengineered climates. This demonstrates the importance of irrigation and breeding for tolerance to water stress as adaptation methods in all futures. Analysis of global rainfall under marine cloud brightening has the potential to significantly reduce the impact of climate change on global wheat and groundnut production. The study was a cross country study and there is need for a country specific study like Nigeria which this study captures.

Theoretical Framework

Social-Technical Systems Theory

Socio-Technical Systems Theory (STS) provides a valuable lens for examining the intersection between cloud seeding and national security, particularly in relation to food security, water augmentation, and policy frameworks. STS theory emphasizes the interdependence between technology and social systems, underscoring that technological interventions like cloud seeding are embedded in broader social, political, and environmental contexts (Bijker et al., 1987). This theory highlights how cloud seeding, while a technological process aimed at enhancing rainfall, is deeply connected to policy development, stakeholder cooperation, and risk management, all of which are critical to achieving national security objectives.

STS theory posits that technology is not developed or implemented in isolation but is shaped by and shapes the social systems in which it is used (Geels, 2004). In the case of cloud seeding, the technology is a part of a socio-technical system designed to address water scarcity, particularly in drought-prone regions. Cloud seeding is aimed at increasing water availability, which is vital for food security as agriculture relies heavily on water for irrigation. However, the success of this technology is contingent upon a comprehensive socio-technical framework that includes not only the technological process but also policies governing its deployment, environmental monitoring, and community engagement.

In many regions, water scarcity poses a significant threat to national security, leading to conflicts over water resources, destabilized food supplies, and population displacement. STS theory highlights that cloud seeding, as a form of water augmentation, must be integrated into existing water management systems and governed by policies that ensure equitable water distribution and environmental sustainability (Smith & Stirling, 2008). Water security directly influences food security, as water scarcity can lead to agricultural shortfalls, increased food prices, and, in extreme cases, social unrest. Cloud seeding offers a technological means to address these issues, but its success relies on how well the technology is managed within broader socio-political systems.

STS theory further helps explain how cloud seeding can enhance food security by ensuring a steady water supply for agriculture (Markard et al., 2012). Given the growing pressures of climate change, cloud seeding provides a mechanism for weather modification that can help stabilize agricultural outputs, particularly in drought-affected areas. However, STS theory emphasizes that technological solutions like cloud seeding need to be accompanied by broader agricultural policies, including those that promote sustainable water use and resilient farming practices. The technology alone cannot solve food security issues unless integrated within a system that includes agricultural support, water governance, and environmental conservation.

STS theory also helps highlight the challenges and risks associated with cloud seeding, particularly in relation to national security. Cloud seeding introduces technical risks (e.g., unintended changes in weather patterns) and social risks (e.g., public mistrust, geopolitical tensions) that must be carefully managed. According to STS, the technology is only one part of a broader socio-technical system that includes risk management, public engagement, and continuous policy development (Smith et al., 2010). For example, while cloud seeding can mitigate drought, poorly regulated or uncoordinated weather modification efforts could lead to environmental damage or international disputes over altered weather patterns. To address these challenges, policymakers must develop transparent, inclusive, and adaptive frameworks that allow for continuous assessment and refinement of cloud seeding practices.

Research Methodology

This study adopted exploratory research design while making use of secondary data generated via journal publications, internet, library, and other documented materials relevant to the study of socioeconomics disconnect on terrorism in northeastern Nigeria. The research is conducted by examining literature concerning cloud seeding, national security, climate change, cloud seeding, and cloud seeding challenges. The literature was obtained through searches in publicly available material, literature from non-serial publications, official reports, and conferences particularly if they have been cited by other references.

Discussion of Findings

The findings from quantitative and review of literature on the intersections between cloud seeding challenges as a construct of national security confirms that cloud seeding challenges poses a threat to national security in Nigeria. This position may be informed by dearth of cloud seeding awareness among Stakeholders, absence of infrastructure availability, non existence of Government Policies on cloud seeding, absence of Funding, dearth of Government-Private Sector Collaboration towards cloud seeding, absence of projected Technical Expertise, and Environmental Risks. Findings from this study align with previous study of Anuar et al. (2024); Ćurić and Janc (2014).

The result gotten from both empirical literature and quantitative analysis affirmed that there exist interconnectedness between Cloud seeding and Food Security; benefits such as increased agricultural productivity, reduced drought-related losses outweighing implementation costs alongside evidence that water stress, rather than heat stress, is the main cause of crop failure in current, future and geoengineered climates. The adoption of Cloud Seeding in ensuring food security can therefore not be ignored. This position confirmed earlier submission of Essien (2023); Parkes et al. (2015); who variously established links between cloud Seeding and food security

Conclusion

i. The study's findings underscore that cloud seeding in Nigeria is hindered by significant challenges, which collectively pose a threat to national security. These challenges include a lack of awareness among stakeholders, inadequate infrastructure, an absence of governmental policies, insufficient funding, weak collaboration between government and the private sector, limited technical expertise, and potential environmental risks. The implications of these challenges are far-reaching, as they limit the country's ability to leverage cloud seeding as a viable solution for water scarcity, agricultural productivity, and climate resilience.

ii. The study concludes that there is a significant and interconnected relationship between cloud seeding and food security in Nigeria. Findings reveal that the adoption of cloud seeding offers substantial benefits, including enhanced agricultural productivity and mitigation of drought-related losses, which outweigh its implementation costs. The evidence underscores that water stress, rather than heat stress, is the primary factor driving crop failures under current, future, and geoengineered climatic conditions.

Recommendations

Based on the conclusions of this study, the following recommendations are made;

i. That North East, North central and west development Commission and the Federal government should be deliberate to establish research initiatives to focus on exploring innovative and sustainable cloud seeding techniques suited to Nigeria's climate and environmental context. This could be done by establishing partnership between the government and private sector entities to promote innovation, resource sharing, and operational efficiency in cloud seeding initiatives.

ii. Government in arid and semi arid zones of Nigeria should employ Cloud Seeding as a Strategic Water Management Tool and cloud seeding should be institutionalize within Nigeria’s water resource management policies. This will also go along way to mitigate against climate change and promote food resilience of the northern region and Nigeria as a nation.

References

Abshaev, A. M., Flossmann, A., Siems, S. T., Prabhakaran, T., Yao, Z., & Tessendorf, S. (2022). Rain enhancement through cloud seeding. In *Unconventional Water Resources* (pp. 21-49). Cham: Springer International Publishing.

Al-Mazroui, A. (2021, March 17). UAE to test cloud-busting drones to boost rainfall. BBC.com. Retrieved from https://www.bbc.com/news/ technology-56428984. Accessed October 9, 2024.

Ambaum, M. (2024, April 17). What is cloud seeding and did it cause record rainfall in Dubai? *SkyNew.* Retrieved from https://news.sky.com/story/what-is-cloud-seeding-and-did-it-cause-record-rainfall-in-dubai-13117432. Accessed October 8, 2024.

Anuar, S. N. S., Narashid, R. H., Razak, T. R., Hashim, S., Rahim, A.& Bohari, S. N. (2024). Cloud Seeding Potential Areas From Remote Sensing of Low-Level Cloud," 2024 20th IEEE International Colloquium on Signal Processing & Its Applications (CSPA), Langkawi, Malaysia, 2024, pp. 35-40, doi: 10.1109/CSPA60979.2024.10525531.

Beck, U. (1992). *Risk Society: Towards a New Modernity*. SAGE Publications.

Bijker, W. E., Hughes, T. P., & Pinch, T. J. (1987). *The Social Construction of Technological Systems*. MIT Press.

Ćurić, M., & Janc, D. (2014). Tendencies for the amounts of chemical material used for cloud seeding in Serbia*. Theor Appl Climatol, 115,* 609–614. https://doi.org/10.1007/s00704-013-0922-0

Doliner, A. (2021, Jul 21). Dubai Creates Fake Rain Using Drones to Battle 122 Degree Heat. *Newsweek.* Retrieved from https://www.newsweek.com/dubai-creates-fake-rain-using-drones-battle-122-degree-heat-1611887. Accessed October 12, 2024.

ENMOD. (2021). Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD)–UNODA. 5-29

Essien, M. (2024). Evaluation of cloud seeding techniques for precipitation enhancement. *Global Journal of Climate Studies*, *1*(1), 53 –. Retrieved from https://forthworthjournals.org/journals/index.php/GJCS/article/view/85

Faouzi, A. (2024, Aug. 25). Morocco's Cloud Seeding Plans Raise Concerns in Spain. *Morrocos World News.* Retrieved from https://www.moroccoworldnews.com/2024/08/364756/moroccos-cloud-seeding-plans-raise-concerns-in-spain. Accessed October 12, 2024.

Fleming, J. R. (2010). *Fixing the Sky: The Checkered History of Weather and Climate Control*. Columbia University Press.

Flossmann, A. I., Wobrock, W., Höller, H., & Yair, Y. (2019). *The Challenges of Weather Modification: Understanding the Complexities of Cloud Seeding*. Meteorological Applications.

Freeman, C. (1987). *Technology Policy and Economic Performance: Lessons from Japan*. Pinter Publishers.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, *33*(6-7), 897-920.

Ghosh, S. (2019, Aug 1). What is cloud seeding? *Mongabay.com.* Retrieved from https://india.mongabay.com/2019/08/what-is-cloud-seeding/ Acces sed October 12, 2024.

Gleick, P. H. (1993). Water and conflict: Fresh water resources and international security. *International Security*, *18*(1), 79-112.

Gray, S. (2024, April 17). Cloud seeding did not cause Dubai floods. Reading.co.uk. Retrieve from https://www.reading.ac.uk/news /2024/Expert-Comment/Cloud-seeding-did-not-cause-Dubai-floods-expert-says. Accessed October 12, 2024.

Hill, S. A., & Ming, Y. (2012). Nonlinear climate response to regional brightening of tropical marine stratocumulus. *Geophysical Research Letters, 39*(15), L15707. doi:10.1029/2012GL052064. S2CID 128599895.

Homer-Dixon, T. (1999). *Environment, Scarcity, and Violence*. Princeton University Press.

Jasanoff, S. (2004). *States of Knowledge: The Co-Production of Science and Social Order*. Routledge.

Jung, W., Cha, J. W., Reum Ko, A., Chae, S., Ro, Y., Hwang, H. J., Kim, B., Ku, J. M., Chang, K., & Lee. C. (2022). Progressive and prospective technology for cloud seeding experiment by unmanned aerial vehicle and atmospheric research aircraft in Korea. *Advances in Meteorology, 2022*(1) 3128657. https://doi.org/10.1155/2022/3128657

Khalid, M. (2020). *Weather Modification in the UAE: Cloud Seeding as a Strategy for Water Augmentation*. Journal of Arid Environment Studies, 22(3), 145-160.

LaCapria, K. (2016, March 17). HAARPing On; The government didn't quietly admit to modifying weather in California; cloud seeding is a well-documented effort to counteract the effects of drought (and isn't related to chemtrails). *Snopes.com*. Accessed October 14, 2024.

Lasrson R. B. (2016). Governing water augmentation under the watercourse convention. *Water Int., 41*, 866-882

Latour, B. (1987). *Science in Action: How to Follow Scientists and Engineers Through Society*. Harvard University Press.

Liu, M. (2010, March 13). Melinda Liu: Can China Control Olympics Weather?. *Newsweek*. Retrieved from https://www.newsweek.com/melinda-liu-can-china-control-olympics-weather-110875. Accessed October, 12, 2024.

Lundvall, B.-Å. (1992). *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. Pinter Publishers.

Mahmoud, M. I., Ibrahim, E. S., Ahmed, B., Arodudu, O. T., Abubakar, J. B., Dang, B. A., Shaba, H. A., & Shamaki, S. B. (2022). Desert Encroachment Monitoring in North-Eastern Nigeria. Presented at the United Nations/Austria Symposium on Space Science and Technology Application 13th-15th September. United Nations Office for Outer Space Affairs (UNOOSA)

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, *41*(6), 955-967.

Matthew, R. A. (2002). Environmental security: Demystifying the concept, clarifying the stakes. *Environmental Change and Security Program Report*, 8(1), 3-8.

Mazur, B. (2022). The Hidden Costs Behind Cloud Seeding, Ignitec - Product Design, Research, and Technology Consultancy, Ignitec, Bristol. Retrieved from https://www.ignitec.com/insights/the-hidden-costs-behind-cloud-seeding/ Accessed October 12, 2024.

Mazzucato, M. (2013). *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*. Anthem Press.

McNaughton, D. L., & Allison, J.C.S. (1982). Effect of cloud-seeding on water-stress of maize in Zimbabwe. *The Journal of Weather Modification, 14*(1), 23–34. doi:10.54782/jwm.v14i1.64. S2CID 128737108.

National Center for Biotechnology Information. (2024). PubChem Compound Summary for CID 24563, Silver iodide. Retrieved October 8, 2024 from https://pubchem.ncbi.nlm.nih.gov/compound/Silver-iodide.

Nelson, R. R., & Winter, S. G. (1982). *An Evolutionary Theory of Economic Change*. Harvard University Press.

Nnodim, O. (2020, June 18). 35% Nigeria land mass threatened by desertification –FG. *Punch News*. Retrieved from https://punchng.com/35-nigeria-land-mass-threatened-by-desertification-fg/. Accessed October 12, 2024.

Parkes, B., Challinor, A., & Nicklin, K. (2015). Crop failure rates in a geoengineered climate: Impact of climate change and marine cloud brightening. *Environmental Research Letters, 10*(8). DOI 10.1088/1748-9326/10/8/084003

Rauber, R. M., Geerts, B., & Xue, L. (2019). Wintertime orographic cloud seeding-a review. *Journal of Applied Meteorology and Climatology, 58*(10), 2117–2140.

Rip, A., & Kemp, R. (1998). Technological Change. In Rayner, S. & Malone, E. (Eds.), *Human Choice and Climate Change* (pp. 327-399). Batelle Press.

Rogers, E. M. (2003). *Diffusion of Innovations* (5th ed.). Free Press.

Rubin, A. J. (2022, Aug. 28). Cloud Wars: Mideast Rivalries Rise Along a New Front. *NewYork Times.* Retrieved from https://www.nytimes.com/2022/08/28/world/middleeast/cloud-seeding-mideast-water-emirates.html. Accessed October4, 2024.

Sachs, J. (2012). *The Age of Sustainable Development*. Columbia University Press.

Simon, M. (2022). Governing Cloud Seeding in Australia and the United States: Lessons for Regional Solar Radiation Management. Being a project submitted for Submitted in fulfilment of the requirements for the L9A- Doctor of Philosophy (Law) University of Tasmania

Smit, E. C. (2015). Geoengineering: Issues Of Accountability In International Law. Retrieved from https://scholars.law.unlv.edu/cgi/viewcont ent .cgi?params =/context/nlj/article /1604/&path_info=15_20 Nev._20L.J._201060_2C_20Smit.pdf Accessed October 12, 2024.

Smith, A., & Stirling, A. (2008). Social-ecological resilience and socio-technical transitions: critical issues for sustainability governance. *Ecology and Society*, *13*(2), 11.

Smith, A., Voß, J., & Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Research Policy*, *39*(4), 435-448.

The Humanitarian. (2004, May 20). Cloud seeding could be expanded across the Sahel. *The Humanitarian.* Retrieve from https://www.thenewhumanitarian.org/news/2004/05/20-1. Accessed October 13, 2024.

UNDP. (1994). *Human Development Report 1994*. United Nations Development Programme.

Weather Modification Association. (2010). Position on the Environmental Impact of using Silver Iodide as a Cloud Seeding Agent. Retrieved from September 11, 2009.

Weber, P. (2022, August 29). Middle East and North Africa are in a dubious arms race to make it rain through cloud seeding. *The Week.* Retrieved from https://theweek.com/north-africa/1016239/middle-east-and-north-africa-are-in-a-dubious-arms-race-to-make-it-rain. Accessed October 2, 2024.

Weiser, M. (2014, October 6). Cloud seeding, no longer magical thinking, is poised for use this winter *The Bee.* Retrieved from https://www.sacbee.com/news/local/article2582373.html#storylink=cpy. Accessed October 4, 2024.

Winner, L. (1980). *Do Artifacts Have Politics? Daedalus, 109*(1), 121–136.

Winner, L. (1986). *The Whale and the Reactor: A Search for Limits in an Age of High Technology*. University of Chicago Press.

Wondie, M. (2023). Modeling cloud seeding technology for rain enhancement over the arid and semiarid areas of Ethiopia. *Research Article*, *9*(4). e14974. https://www.cell.com/heliyon/fulltext/S2405-8440(23)02181-3

World Meteorological Organization (WMO)., Flossmann A. I., Manton M., Abshaev A., Bruintjes R., Murakami M., Prabhakaran T., & Yao, Z. (. (2018). Peer Review Report on Global Precipitation Enhancement Activities, 2018, WWRP, Geneva, Switzerland.

Zhou, Y., & Wang, S. (2019). Weather modification practices in China: The role of cloud seeding in water resource management. *Journal of Environmental Sciences, 31*(2), 230-245.