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Assessing the influence of policy frameworks on the adoption of Cloud Seeding Technology in northeastern, Nigeria

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Abstract
The need to gain critical academic insights into the interplay between technological adoption and governance in addressing water scarcity and climate resilience challenges, led this study to assesses the influence of policy frameworks on the adoption of cloud seeding technology in northeastern Nigeria, focusing on its role in water augmentation and implications for national security. This study adopts survey research design, population of the study; Adamawa and Borno States totals 11,012, 600 and by scientific sampling technique determination of Krejcie and Morgan (1970) study arrive at a sample size of 384 on targeted population. The study utilized primary data source elicited from a structured five Likert scale questionnaire, while descriptive statistics was used for analysis of result. Findings reveal overwhelming support (97–98% agreement) for cloud seeding as a viable tool for replenishing water bodies, mitigating drought, slowing desertification, stabilizing rainfall patterns, and reducing resource-driven social tensions in Northeastern Nigeria. However, results simultaneously indicate significant structural weaknesses in policy clarity, public awareness, funding allocation, institutional coordination, and research engagement, with 98–99% of respondents expressing dissatisfaction with existing frameworks. While stakeholders strongly endorse the technical and environmental potential of cloud seeding, they perceive Nigeria's governance architecture as insufficient to support effective implementation. The study therefore recommends the development of a comprehensive national cloud seeding policy framework, dedicated funding mechanisms, strengthened institutional coordination, and enhanced public and policymaker awareness campaigns. It further advocates increased collaboration between government agencies and tertiary institutions to promote research-driven implementation.
Keywords: Cloud Seeding, Environmental Security Theory, Policy Framework, Water augmentation

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).

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Despite the potential benefits of cloud seeding, many countries, including Nigeria, lack the necessary policy framework to effectively implement and regulate weather modification efforts. Without appropriate policies and guidelines, cloud seeding initiatives may be hampered by legal, ethical, and environmental concerns. Additionally, the absence of a coordinated approach to weather modification means that Nigeria is not fully capitalizing on the benefits that cloud seeding could bring in terms of enhancing food and water security.

Furthermore, the technical challenges associated with cloud seeding, including the lack of expertise, absence of infrastructure, and dearth of economic leverages to execute such lofty concept, present a significant obstacle to its adoption in Nigeria. Many countries with successful cloud seeding programs have invested in cutting-edge technology and the development of skilled personnel. However, Nigeria faces infrastructural fragility and a shortage of trained meteorologists and engineers capable of managing and deploying cloud seeding operations effectively (Chiedu, 2023). The country's limited understanding and adoption of cloud seeding further compound these challenges, making it essential to address both the technical and infrastructural deficits to realize the potential of cloud seeding in enhancing national security (Duke-Abiola et al., 2025).

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

However, Nigeria lacks a comprehensive framework to effectively engage in cloud seeding as a strategic tool for national security. Surprisingly, the concept is strange to all options to mitigate desertification and unwholesome pattern of insecurity in the Lake Chad basins. The absence of policies and guidelines to regulate and promote weather modification initiatives leaves a gap in addressing the pressing concerns of drought, water scarcity, and food insecurity.

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 a 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 implementation constraints, 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.

Statement of the Hypothesis

The study in a bid to achieve the objective of this study tested the following null hypothesis

i. Cloud seeding has no relationship with water augmentation in Nigeria.

ii. Policy frameworks have no relationship with cloud seeding adoption in Nigeria.

Literature Review

Conceptual Framework

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)

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).

Electrical Charges

Under the electrical charges of achieving Cloud Seeding, drones are engaged to release an electrical charge into clouds, prompting them to coalesce and create rain. The technology is reportedly favored compared to other forms of cloud seeding because it uses electricity to generate rain rather than chemicals (Doliner, 2021). The water table is sinking drastically in UAE and the purpose of this is to try to help with rainfall. Dubai has plenty of clouds, efforts to persuade the water droplets in them to merge and stick together, "like dry hair to a comb" when it meets static electricity. When the drops merge and are big enough, they will fall as rain. Equipped with a payload of electric-charge emission instruments and customised sensors, these drones fly at low altitudes and deliver an electric charge to air molecules, which should encourage precipitation (Al-Mazroui, 2021).

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 advances the understanding of cloud seeding mechanisms within the broader context of weather modification.

However, Satellite imagery suggests that the Dubai flooding and rainstorms was caused by a mesoscale convective system. 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)

Concept of 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.

Legal frameworks primarily focus on prohibiting the military or hostile use of weather modification techniques, leaving the ownership and regulation of cloud-seeding activities to national discretion. While there exist skepticism over its efficacy and environmental impact, cloud seeding continues to be explored and applied in regions worldwide as a tool for weather modification. Governments across the world have long invested in these technologies and developed legal frameworks to govern cloud seeding activities. Cloud seeding and regional SRM bear enough similarities to warrant an in-depth assessment of existing legal and institutional arrangements for cloud seeding, and the extent to which they can inform the governance of SRM technologies, such as MCB.

The study employed adaptive governance principles in two Australian states and two American states. These case studies show that regional SRM regimes require (1) legal arrangements to facilitate greater interactions between institutions across scales of governance, to account both for the scale of deployment and the scale of impacts; (2) broader participation of relevant stakeholders at an early stage of research; (3) flexible legal mechanisms built into the decision-making to foster iterative learning; and (4) mechanisms to prevent and resolve potential conflicts (Simon, 2022).

For cloud seeding to effectively contribute to national security, it must be embedded within a robust policy framework which emphasised the importance of governance in managing environmental risks (Homer-Dixon, 1999). Cloud seeding, as a technical solution, requires clear regulations to guide its deployment, environmental monitoring, and cross-border coordination. Policies must address the equitable distribution of water resources, transparency in decision-making, and risk management strategies to avoid unintended consequences. Effective governance ensures that cloud seeding supports national security objectives, such as water and food security, without creating new vulnerabilities or conflicts.

Policymakers must integrate cloud seeding into national water management and agricultural strategies, ensuring that the technology is used in a way that promotes long-term sustainability. This requires coordination between government agencies, scientific experts, and international bodies to address both the environmental and geopolitical dimensions of cloud seeding.

Existing international legislation

The Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD) is the only international framework related to the regulation of weather and climate modification technologies. Developed after cloud-seeding operations were conducted during the Vietnam War and the Cold War (Larson, 2015), the convention's scope of application solely encompasses military or any other hostile uses of weather modification technologies.[108] Indeed, the use of weather modification programs for peaceful purposes is not prohibited by the treaty. ENMOD has been criticised for its many weaknesses, notably regarding the vagueness and ambiguity of notions leaving room for various interpretations (Fleming, 2010)

Framework

Operation Popeye's goal was to increase rainfall in carefully selected areas to deny the Vietnamese enemy, namely military supply trucks, the use of roads by; softening road surfaces, causing landslides along roadway, Washing out river crossings, Maintaining saturated soil conditions beyond the normal time span. The goal of the operation was to extend days of rainfall by about 30 to 45 days each monsoon season.

Constrains of Cloud Seeding in Nigeria

Challenges Finally, the study would assess the constraining factors affecting the success of cloud seeding in Nigeria, including financial, technological, and environmental challenges. Understanding these factors is critical for determining the feasibility of scaling cloud seeding as a long-term solution for national security. For example, issues such as the high cost of cloud seeding operations, limited technical expertise, and concerns over unintended environmental consequences could hinder the broader adoption of the technology. By addressing these constraints, the study would offer solutions and policy recommendations to overcome these barriers, ensuring that cloud seeding can play a sustainable role in enhancing Nigeria's national security, food security, and water resources.

Empirical Review

Cloud seeding and water augmentation

Wondie (2023) examined the nexus between technology for rain enhancement over the arid and semiarid areas and modeling cloud seeding of Ethiopia. The study employed different relevant measurements including ground-based as well as reanalysis data from 2021 to 2022 to improve relevant cloud-seeded models, which entails different error metrics. Findings that emanated from the study revealed that relative precipitation (RP) after the application of cloud-seeded per before the application of cloud-seeded during spring, summer, and autumn is found 1.31, 0.98, and 1.03 respectively. The changing precipitation between cloud seeded and before seeded for spring, summer, and autumn is found at 1.38, −0.19, and 0.11 mm respectively; whereas changing temperature is found at 1.08, 1.78, and −1.06 k respectively. The study concluded that cloud-seeded technology is effective over Ethiopia. Study was done in Ethiopia hence the need to use Nigeria's datasets. The study only consider water augmentation while this study capture policy framework and food security interconnectedness with cloud seeding in Nigeria.

Policy frameworks and Cloud Seeding adoption

Jung et al. (2022) reviewed the usage of prospective technology for cloud seeding experiment by unmanned aerial vehicle and atmospheric research aircraft in Korea. The study engaged a UAV to spray cloud seeding material (calcium chloride), and the aircraft monitored the clouds in the southern part of the Korean Peninsula. Cloud observation equipment in the aircraft indicated an increase in the number concentration and average particle size of large cloud particles after the seeding. The result that emanated from the study showed that rain was observed after seeding, and 0.5 mm was recorded, including natural and mixed precipitation from the cloud seeding. The study further revealed rapid increase in the number of raindrops and vertical reflectivity which confirmed the possibility of cloud seeding using UAVs and atmospheric research aircraft. The effects of cloud seeding are indicated through the increased number concentration and size of cloud particles, radar reflectivity, and ground-based precipitation detection. The study was limited to rain and water availability through weather modification while this study further capture policy issues in relation State yet to engage cloud seeing

Simon (2022) interrogated in a crosscountry studies, extent to which cloud seeding laws can be used as a basis for governing regional solar radiation management activities. Solar radiation management (SRM) is being proposed to reflect a portion of sunlight away from Earth, to delay temperature increases while the international community accelerates mitigation actions. The study submitted that research and deployment of these novel technologies requires the development of governance frameworks to manage associated risks and uncertainties. Whereas attempts to influence the climate system at a global scale will require international governance, domestic arrangements may be more appropriate to govern small-scale field testing and regional SRM applications. The study focused more on Solar radiation management while this study focus on cloud seeding.

Theoretical Framework

Environmental Security Theory

Environmental Security Theory gained traction under the works of Homer-Dixon (1999) who connects environmental challenges such as water scarcity and climate change to national security concerns. According to this theory, environmental stress can exacerbate social and political tensions, and cloud seeding offers a tool to prevent such conflicts. By mitigating drought and enhancing agricultural production, the technology supports national stability and reduces the potential for resource-driven conflicts. Cloud seeding, as a technological intervention to mitigate droughts, directly addresses these environmental threats by increasing water availability for agricultural and industrial purposes.

Environmental Security Theory provides a powerful framework for understanding the relationship between cloud seeding and national security, particularly in the context of food security, water augmentation, the challenges of cloud seeding, and the need for effective policy frameworks. The theory posits that environmental stressors, such as resource scarcity, climate change, and ecosystem degradation, pose significant threats to the stability and security of nations. By addressing environmental vulnerabilities, cloud seeding emerges as a tool that can enhance national security through mitigating water shortages, improving agricultural productivity, and alleviating resource-driven tensions.

Cloud seeding, a weather modification technique that stimulates precipitation, is increasingly viewed as a strategic measure to address water scarcity a key component of environmental security. Environmental Security Theory, as articulated by scholars like Thomas Homer-Dixon (1999), highlights how resource scarcity, particularly water, can exacerbate social tensions and lead to conflict. In regions where water is scarce, such as arid and semi-arid areas, cloud seeding offers a way to increase water availability for agriculture, industry, and human consumption. This intervention aligns with national security objectives by reducing competition over dwindling water resources, thus potentially preventing conflict over resource distribution.

Food security is another area where cloud seeding can play a significant role in the context of Environmental Security Theory. Agriculture is highly dependent on water availability, and in drought-prone areas, insufficient rainfall can lead to reduced crop yields, famine, and social instability. According to Peter Gleick (1993), water scarcity has direct implications for food production, which in turn affects national security.

Cloud seeding helps mitigate the risks of drought by enhancing rainfall, thus ensuring stable agricultural production. By stabilizing food supplies, cloud seeding contributes to national security by reducing the likelihood of food-related unrest or economic instability that might arise from food shortages.

Despite its potential, cloud seeding faces several challenges that Environmental Security Theory helps highlight. These challenges include the unpredictability of weather patterns, the potential for unintended environmental impacts, and the geopolitical concerns of altering weather across borders. As Richard Matthew (2002) argues, the environmental security framework must account for the risks associated with technological interventions, especially when these interventions can create new forms of environmental stress. Cloud seeding, for instance, can lead to unequal distribution of rainfall, potentially causing downstream water shortages or flooding in neighboring areas, thus heightening international tensions. This makes it imperative for nations to consider the broader ecological and political consequences of such interventions.

For cloud seeding to effectively contribute to national security, it must be embedded within a robust policy framework. Environmental Security Theory emphasizes the importance of governance in managing environmental risks (Homer-Dixon, 1999). Cloud seeding, as a technical solution, requires clear regulations to guide its deployment, environmental monitoring, and cross-border coordination. Policies must address the equitable distribution of water resources, transparency in decision-making, and risk management strategies to avoid unintended consequences. Effective governance ensures that cloud seeding supports national security objectives, such as water and food security, without creating new vulnerabilities or conflicts.

Incorporating cloud seeding into broader national security strategies is essential for addressing the complex interplay between water scarcity, food security, and environmental sustainability. Environmental Security Theory suggests that technological solutions like cloud seeding should be seen as part of a larger strategy to address resource scarcity and environmental stress (Gleick, 1993). Policymakers must integrate cloud seeding into national water management and agricultural strategies, ensuring that the technology is used in a way that promotes long-term sustainability. This requires coordination between government agencies, scientific experts, and international bodies to address both the environmental and geopolitical dimensions of cloud seeding.

Research Methodology

This study engaged a social survey design in assessing Cloud Seeding and National Security in Nigeria particularly in Northwest and Northeast region where aridity is prevalent. This study will involve travelling to randomly selected locations to engage the respondents in a structured interview physically. This study was carried out in Abuja with ample visitation to the Federal Capital Territory, Northeast, and the Northwest States in Nigeria. Abuja, Borno and Yobe State purposively chosen because of the presence of policy makers, Nigeria Metreological Stations Headquarters. and the apparent trends of aridity in both the Nortwestern and North eastern states of Nigeria; particularly Borno State and Yobe Sates.

This study purposively choose Askira/Uba and Portiskum Local Government Area of Borno and Yobe States respectively in Northeastern Nigeria. The purposive choice of this location is informed by the prevalence of aridity and the proximal effect of the two sub basins that drain into Lake Chad located in Borno and Yobe States, which falls within Latitudes 10º N to 14º N and Longitudes 10ºEto 15ºE. All these made the purposively chosen sites interesting for this research.

Data was elicited from the target population of the study; Nigerian Meteorological Agency (NiMet) with 157 Meteorological Stations covering Nguru, Potiskum, Maiduguri, Katsina, and Yola amongst others, Federal and State Ministry of Agriculture and Food Security,National Climate Council, National Agency for the Great Green Wall (NAGGW).Federal and State Ministry of Livestock Management, Office of the National Security Advisers, Federal Ministry of Humanitarian Affairs and Poverty Alleviation, North East Development Commission, University of Maiduguri, Nigeria Army University Biu. Visitation shall be made to community leaders, clerics, NGOs and CSO. This study employed scientific sampling technique determination of Krejcie and Morgan (1970) that recommends a sample size of 384 for a population above 1 million.

Data Analysis and Results

Reliability and Validity Test

Reliability of the primary data is checked through Cronbach’s alpha. Reliability of the survey instrument is evaluated through Cronbach Alpha. The study computes separate and combine reliability estimates, which are similar to the normally used coefficient alpha statistics. Cronbach value beyond (**α** = .7) signifies acceptable reliability.

Table One : Cronbach’s Alpha Test Results Summary

Variable	**Cronbach Alpha**	**Number of Items**
Cloud Seeding and National Security (CSNS)	0.818	7
Cloud Seeding and Water Augmentation (CSWA)	0.890	7
Cloud Seeding and Policy frameworks (CSPF)	0.941	7
Total Questions	0.931	21

Source: Extracted from SPSS Output, 2024.

The measurement scales’ computed Cronbach’s Alpha (α) results in table 3 reveals that Cloud Seeding and National Security (CSNS) revealed Cronbach’s Alpha (α) of 0.818, while Cloud Seeding and Water Augmentation (CSWA) displayed a Cronbach’s Alpha value of 0.890 and Cloud Seeding and Policy frameworks

(CSPF) revealed Cronbach's Alpha (α) of 0.941. The overall questions translated to a Cronbach Alpha (α) of 0.931. The measurement scales were reliable as all the Cronbach's value are well above 0.6 threshold which is the recommended coefficient for a given research instrument.

Table Two: Summary of Primary Data on Cloud Seeding and Water Augmentation Using Five Point Likert's Scale

Cloud Seeding and Water Augmentation	SA	A	N	SD	D	STD DEV	MEAN	Total
Cloud seeding can replenish rivers, reservoirs, and underground water sources in Northeastern Nigeria.	181	192	2	6	3	0.7067	3.5469	384
	47%	50%	1%	2%	1%			1
Integrating cloud seeding into regional water resource management will reduce droughts in Northeastern Nigeria.	199	173	6	4	2	0.7408	3.1458	384
	52%	45%	2%	1%	1%			1
Cloud seeding has proven to be effective in augmenting water resources in drought-prone areas.	188	184	5	5	2	0.6678	3.5217	384
	49%	48%	1%	1%	1%			1
Cloud seeding presents minimal environmental risks for water augmentation in the region.	201	177	1	2	3	2.789	3.3622	384
	52%	46%	0%	1%	1%			1
Cloud Seeding can reduce increasing desertification of northeaster Nigeria	192	181	3	5	3	3.5352	3.3152	384
	50%	47%	1%	1%	1%			1
Water scarcity as factor of social tension can be rolled back by Cloud Seeding	186	192	1	3	2	3.1127	3.3914	384
	48%	50%	0%	1%	1%			1
Cloud seeding by water augmentation can mitigate climate change in the Northeastern Nigeria.	201	176	1	2	4	3.2817	3.1094	384
	52%	46%	0%	1%	1%			1

Source: Field Survey, 2024.

Field responses on cloud seeding and water augmentation in Northeastern Nigeria indicate overwhelmingly positive perceptions, with 97–98% agreement across all items. Respondents expressed strong confidence in its ability to replenish rivers and groundwater (Mean = 3.55, SD = 0.71), augment water in drought-prone areas (Mean = 3.52, SD = 0.67), and support regional water management to reduce drought impacts (Mean = 3.15, SD = 0.74). It was also widely viewed as capable of slowing desertification, mitigating climate change effects, and reducing water-related social tensions an important consideration in a conflict-prone region. Additionally, cloud seeding was perceived as environmentally sustainable with minimal ecological risks (Mean = 3.36, SD = 2.79). The fact that mean values exceed standard deviations across all variables indicates low dispersion and strong consensus, reinforcing the reliability of the findings. Overall, the data supports integrating cloud seeding into the region's climate adaptation and water governance strategies, while recognizing that effective implementation will require addressing technical and institutional challenges.

Table Three: Responses Frequency on Cloud Seeding and Policy frameworks in Nigeria using Five Point Likert's Scale

	Cloud Seeding and Policy frameworks in Nigeria	SA	A	N	SD	D	STD DEV	MEAN	Total
1	There is sufficient public awareness about cloud seeding as a policy-driven solution for environmental challenges	3	2	3	196	180	0.7067	3.5469	384
		1%	1%	1%	51%	47%			1
2	Policymakers in Nigeria have a clear understanding of the potential benefits of cloud seeding.	2	2	2	181	197	0.7408	3.1458	384
		1%	1%	1%	47%	51%			1
3	Northeast Region Development Commission has consideration for Cloud seeding	2	1	2	188	184	0.6678	3.5217	377
		1%	0%	1%	50%	49%			1
4	Government has allocated sufficient resources to develop cloud seeding	1	2	4	198	179	0.789	3.3622	384
		0%	1%	1%	52%	47%			1
5	Policies guiding cloud seeding in Nigeria are comprehensive to ensure implementation.	3	1	2	189	189	0.5352	3.3152	384
		1%	0%	1%	49%	49%			1
6	Tertiary institutions in northeastern Nigeria are advancing the Cloud Seeding technology	1	2	2	189	190	0.1127	3.3914	384
		0%	1%	1%	49%	49%			1
7	The existing policy framework supports the adoption of cloud seeding technologies.	2	3	2	176	201	0.2817	3.1094	384
		1%	1%	1%	46%	52%			1

Source: Field Survey, 2024.

The findings on cloud seeding adoption and policy frameworks in Nigeria reveal overwhelming dissatisfaction with the current institutional and policy environment, with 98–99% of respondents expressing disagreement across all key indicators. There is a strong perception of insufficient public awareness (Mean = 3.55, SD = 0.71) and limited policymaker understanding of cloud seeding's strategic benefits (Mean = 3.15, SD = 0.74), indicating both societal and elite-level knowledge gaps. Respondents further believe that the Northeast Development Commission has not meaningfully prioritized cloud seeding (Mean = 3.52, SD = 0.67), government funding is inadequate (Mean = 3.36, SD = 0.79), and existing policies lack clarity and structural robustness for effective implementation (Mean = 3.31, SD = 0.54). Tertiary institutions are also perceived as minimally engaged in advancing research and innovation (Mean = 3.39, SD = 0.11), reinforcing the broader view that Nigeria lacks the institutional ecosystem required for adoption. With mean values consistently higher than standard deviations, responses demonstrate strong consensus and low variability, underscoring the reliability of these perceptions. Overall, the data points to systemic weaknesses in awareness, funding, legislative design, and institutional coordination, highlighting the urgent need for comprehensive policy reform, capacity building, and research collaboration to position cloud seeding as a viable tool for national security and environmental resilience.

Discussion of Findings

Quantitative expression gotten from this study translate that cloud Seeding has a significant positive impact on Water Augmentation in Nigeria. It indicates nexus between water augmentation and technology for rain enhancement over the arid and semiarid areas and modeling cloud seeding. Studies also reveal existence of relative precipitation after the application of cloud-seeded before and during spring, summer, and autumn. This finding is in line with prior works of Wondie (2023), whose findings reflect that Cloud Seeding has an influencing relationship with water augmentation.

The result that emanated from the regression result situated that there in non existence of Cloud Seeding policy in Nigeria and this has a negative significant impact on national security in Nigeria. The result confirmed the possibility of cloud seeding using UAVs and atmospheric research aircraft. Policy on cloud seeding laws for governing regional solar radiation management activities. Solar radiation management (SRM) is being proposed to reflect a portion of sunlight away from Earth, to delay temperature increases while the international community accelerates mitigation actions. The study submitted that research and deployment of these novel technologies requires the development of governance frameworks to manage associated risks and uncertainties. Whereas attempts to influence the climate system at a global scale will require international governance, domestic arrangements may be more appropriate to govern small-scale field testing. This study aligns with similar findings of Jung et al. (2022); Simon (2022)

Conclusion

Based on the specific objectives, this study concludes that the Northern States Governors Forum and her Development Commissions should Integrate Cloud Seeding as a key component of National Agricultural Strategies. This could be advanced by allocating specific funds in the national budget for cloud seeding programs, ensuring sustained financial support for implementation and maintenance. The study concludes that cloud seeding significantly and positively impacts water augmentation in Nigeria. The findings demonstrate a clear nexus between water augmentation and the application of technology for rain enhancement, particularly over arid and semi-arid regions. Evidence of increased precipitation during spring, summer, and autumn following cloud seeding further underscores its efficacy.

The study also concludes that the absence of a cloud seeding policy framework in Nigeria significantly and negatively impacts national security. The findings emphasize the urgent need for governance structures to regulate the use of emerging technologies such as unmanned aerial vehicles (UAVs) and atmospheric research aircraft for cloud seeding, as well as solar radiation management (SRM) activities.

Recommendations

i. That the Office of the National Security Adviser through a Multi-Agency Task Force and the North East Development Commission should emphasize the urgent need for governance structures to regulate the use of emerging technologies such as unmanned aerial vehicles and atmospheric research aircraft for cloud seeding, as well as solar radiation management activities.

ii. That the Federal Government and the Regional Development Commissions should evolve a national cloud seeding policy framework, incorporating provisions for technology use, operational standards, environmental safeguards, and risk management. Incorporate Emerging Technologies. The need to create a dedicated regulatory agency to oversee cloud seeding, ensuring compliance with established standards and policies. Promote International and Domestic Collaboration

References

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. doi: 10.1109/CSPA60979.2024.10525531.

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

Chiedu, A. (2023, September 17). NiMET DG Highlights NiMET's Experience On Manpower, Brain Drain Issues. *Aviation Monitor*. Retrieved from https://aviationmonitorng.com/nimet-dg-highlights-nimets-experience-on-manpower-brain-drain-issues/. Accessed October 6, 2024

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.

Duke-Abiola, A. Q., Zamani, A. E., & Onibiyo, E. R. (2025). Cloud seeding technology and its potential influence on food security in Nigeria. Unregulated scrap economy and the security of telecommunications infrastructure in Nigeria. *International Journal of Social Science, Management, Peace and Conflict Research, 10*(10), 125-138. https://doi.org/10.63532/IJSMPCR.20251002

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. New York*: Columbia University Press. ISBN 978-0-231-51306-7. OCLC 664234130.

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

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.

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

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.

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.

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.

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

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

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.

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.

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.

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

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.