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Climate Change and Its Impact on Agricultural Productivity in Arid Regions

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Abstract

Climate change is a global phenomenon with far-reaching effects on the environment, economy, and human health. In arid regions, where agriculture is already challenged by limited water resources and extreme temperatures, the impacts of climate change are particularly profound. This paper examines how climate change affects agricultural productivity in arid regions, with a focus on temperature increases, altered precipitation patterns, and water scarcity. It discusses both the direct and indirect effects of climate change on crop yields and farming practices, highlighting strategies for adaptation and mitigation. The paper concludes by emphasizing the need for sustainable agricultural practices and policy interventions to address the challenges posed by climate change in these vulnerable regions.

Keywords : Climate change, agricultural productivity, arid regions, water scarcity, temperature increase, precipitation patterns, crop yields, adaptation strategies, sustainable agriculture, climate-smart agriculture.

1. Introduction

Arid regions, defined by their low precipitation levels and high evaporation rates, are some of the most vulnerable areas to climate change. Agriculture in these regions is heavily dependent on water resources, which are becoming increasingly scarce due to both natural variability and human-induced climate change. According to the Intergovernmental Panel on Climate Change (IPCC), global temperatures are rising, and weather patterns are becoming more erratic, leading to increased frequency and intensity of droughts, floods, and extreme heat events. These climatic changes pose serious risks to agricultural productivity, which is a

key sector in many arid regions of the world, particularly in Africa, the Middle East, and parts of Asia.

The purpose of this paper is to explore the ways in which climate change affects agricultural productivity in arid regions and the strategies that can be employed to mitigate these impacts. The analysis covers changes in temperature, precipitation, and water availability, as well as the broader socio-economic implications for farmers and local communities.

2. Climate Change and Its Effects on Arid Regions

Climate change refers to long-term shifts in temperature, weather patterns, and atmospheric conditions, which are largely driven by human activities such as the burning of fossil fuels, deforestation, and industrialization. In arid regions—areas characterized by low precipitation, high evaporation rates, and limited water resources—these changes pose serious challenges. Arid regions are particularly vulnerable to climate change due to their already harsh environmental conditions, making adaptation and mitigation efforts more critical.

2.1. Temperature Increase

Rising global temperatures are one of the most direct consequences of climate change. Arid regions, where average temperatures are already high, experience even more extreme heat as a result. This temperature increase can stress crops and livestock, reducing agricultural productivity. For instance, heat stress can damage crops like wheat, maize, and rice, which are sensitive to temperature fluctuations. When temperatures exceed a certain threshold, plant growth can be stunted, leading to reduced yields. Additionally, higher temperatures accelerate evaporation, increasing the demand for water in irrigation systems, which already struggle in these regions due to limited water supplies. One of the most significant consequences of climate change is the increase in global temperatures. In arid regions, higher temperatures exacerbate the challenges faced by agriculture. Increased heat stress can reduce the viability of crops, shorten growing seasons, and lower yields. For example, wheat, maize, and rice—staple crops in many arid countries—are highly sensitive to temperature changes. A study by Lobell et al. (2011) found that for every degree Celsius increase in temperature,

global yields of staple crops could decline by 5–10%. In arid regions, where crops are already growing at the edge of their temperature tolerance, even small increases in temperature can have devastating effects.

In addition to directly affecting crop yields, higher temperatures also increase evaporation rates, leading to greater water loss from soil and irrigation systems. This intensifies water scarcity, which is already a pressing concern in many arid regions (Huang, 2016). The combination of higher temperatures and reduced water availability results in reduced agricultural productivity and greater vulnerability for farmers.

2.2. Altered Precipitation Patterns

Another significant impact of climate change in arid regions is the alteration of precipitation patterns. Climate models predict more erratic rainfall, with longer dry spells followed by intense, short bursts of rainfall. This unpredictability makes farming more difficult because it becomes harder to plan for the planting and harvesting of crops. In many arid regions, rain-fed agriculture is the primary source of food production. When rainfall is inconsistent or occurs at the wrong times, it can lead to crop failures and the deterioration of soil quality. Changes in precipitation patterns are another major consequence of climate change that impact agricultural productivity in arid regions. Climate models predict that many arid regions will experience more erratic and unpredictable rainfall, with longer dry periods followed by intense rainfall events (IPCC, 2021). This variability can make it difficult for farmers to plan their planting and harvesting schedules, and it can lead to crop failures when rainfall is insufficient or poorly timed.

For example, in the Middle East and North Africa, regions that are already prone to drought, future projections suggest that rainfall will become more sporadic and less reliable, resulting in significant risks to agriculture (FAO, 2020). The impact of these changes is particularly pronounced in dryland farming systems, where crops depend almost entirely on seasonal rainfall. Inconsistent or insufficient rainfall can lead to crop losses, soil degradation, and the loss of livelihoods for farmers in these areas.

In regions such as the Middle East, North Africa, and parts of Asia, future projections suggest a decrease in overall rainfall, further aggravating water scarcity. When rain does fall, it may come in the form of heavy storms that cause erosion and soil degradation, leaving the land less fertile and reducing its agricultural potential.

2.3. Water Scarcity

Water scarcity is one of the most pressing challenges in arid regions, and climate change exacerbates this issue. As temperatures rise and precipitation becomes more erratic, the availability of freshwater—whether from rivers, lakes, or groundwater—becomes increasingly unpredictable. The situation is made worse by the fact that many arid regions rely heavily on irrigation for agriculture, often drawing on already limited water supplies. Overuse of water resources, compounded by reduced rainfall, leads to the depletion of groundwater reserves and the drying up of rivers and lakes. Water scarcity is perhaps the most pressing issue for agriculture in arid regions, and climate change exacerbates this challenge. According to the UN Water, about 1.2 billion people live in areas where water is scarce, and many of these areas are arid or semi-arid. As temperatures rise and precipitation becomes more unpredictable, groundwater supplies and surface water bodies are increasingly depleted, making it more difficult for farmers to irrigate their crops.

In arid regions, where irrigation is often the primary method of crop production, the availability of water is a limiting factor. A study by Vörösmarty et al. (2010) showed that climate change is contributing to the depletion of water resources in regions like the Middle East and Central Asia, where reliance on irrigation is particularly high. As water becomes scarcer, the cost of irrigation increases, leading to lower profitability for farmers and, in many cases, the abandonment of agricultural lands.

In places such as the Middle East and Central Asia, where agriculture is crucial for food security and economic stability, the growing demand for water is unsustainable. As a result, farmers are forced to rely on expensive, energy-intensive irrigation methods, which are not only costly but also contribute to further environmental degradation.

2.4. Soil Degradation and Desertification

Increased temperatures, altered precipitation, and water scarcity contribute to soil degradation and desertification in arid regions. Soil erosion, loss of soil fertility, and the encroachment of deserts are all linked to the changing climate. Without sufficient rainfall, the land becomes more susceptible to erosion by wind and water. Additionally, the prolonged lack of moisture can lead to a decline in soil organic matter, making it harder for crops to grow. Desertification—the process by which fertile land becomes desert—further exacerbates the inability of land to support agricultural activities, threatening local livelihoods and food security.

2.5. Impact on Livelihoods and Food Security

Agriculture in arid regions is often the primary source of income and food for local populations. As climate change decreases crop yields and livestock productivity, it directly threatens the food security and economic stability of these regions. Smallholder farmers, who are most vulnerable to climate shifts, may struggle to adapt to these changes without access to resources such as irrigation systems, drought-resistant crops, and financial support. In addition, the effects of climate change on agriculture can lead to increased migration from rural areas to urban centers, where employment opportunities may not be available, thereby exacerbating poverty and social instability.

2.6. Increased Frequency of Extreme Weather Events

Climate change is contributing to an increase in the frequency and intensity of extreme weather events, such as droughts, heatwaves, and floods. These events can devastate agricultural systems in arid regions. For instance, droughts can extend for longer periods, leading to crop failures and food shortages. Conversely, when rains do arrive, they may come in intense downpours, causing flash floods that damage crops, erode soil, and destroy infrastructure. These extreme events not only harm the environment but also disrupt local economies and social structures, increasing the vulnerability of communities to future climate shocks.

In summary, climate change exacerbates the existing challenges faced by agriculture in arid regions. Rising temperatures, altered precipitation patterns, and worsening water scarcity all contribute to reduced agricultural productivity. These impacts threaten the livelihoods of farmers, food security, and overall economic stability in these regions. Therefore, effective adaptation and mitigation strategies—such as water-efficient irrigation systems, drought-resistant crops, and sustainable land management—are essential for reducing the vulnerability of arid regions to climate change. Addressing these challenges will require both local and global efforts, including policy changes, technological innovation, and financial investment in climate resilience.

3. Adaptation Strategies

In response to the challenges posed by climate change, farmers in arid regions must adopt strategies to adapt to the changing climate. These strategies include changes in crop selection, improved irrigation techniques, and the use of drought-resistant crops. One effective adaptation strategy is the adoption of agroforestry systems, which integrate trees with crops to reduce soil erosion, enhance water retention, and provide shade, thus helping to mitigate the effects of extreme temperatures and drought (Lehmann et al., 2014).

Another important adaptation strategy is the use of climate-smart agriculture, which involves the use of technologies and practices that increase agricultural productivity in a sustainable manner while reducing greenhouse gas emissions. For instance, drip irrigation systems, which deliver water directly to the roots of plants, are more water-efficient than traditional irrigation methods and can help conserve water in areas with limited resources (Kipkorir & Karimi, 2008).

Adaptation strategies are essential to mitigate the negative impacts of climate change on agricultural productivity, particularly in arid regions where water scarcity, rising temperatures, and altered precipitation patterns exacerbate existing challenges. These strategies aim to increase the resilience of agricultural systems, ensuring food security and sustaining livelihoods in the face of changing environmental conditions. The following are

key adaptation strategies that can help mitigate the adverse effects of climate change in arid regions.

3.1. Water-Efficient Irrigation Systems

Water scarcity is a critical issue in arid regions, where agricultural productivity heavily depends on irrigation. To address this challenge, water-efficient irrigation techniques are essential. Methods such as **drip irrigation** and **sprinkler irrigation** deliver water directly to the plant roots or spread it evenly across the field, minimizing water wastage. **Drip irrigation** is especially effective in arid regions because it reduces evaporation and runoff, optimizing water use. Additionally, **rainwater harvesting** techniques can be implemented to collect and store rainwater during seasonal rains, providing an additional water source during dry periods.

Moreover, **smart irrigation systems** that use sensors and weather forecasts can help farmers determine the optimal amount of water needed at any given time, further reducing water consumption. These systems ensure that water is used efficiently, making it a valuable adaptation strategy in water-scarce environments.

3.2. Drought-Resistant Crop Varieties

The development and use of **drought-resistant crop varieties** are among the most important adaptation strategies for arid regions. These crops are genetically engineered or selectively bred to withstand periods of water stress and higher temperatures, ensuring stable yields even under harsh conditions. Examples of drought-resistant crops include certain varieties of **maize, sorghum, millet, and wheat**, which are specifically cultivated to cope with water shortages.

In addition to drought resistance, **early-maturing crop varieties** can be adopted to reduce the risk of crop failure due to unpredictable rainfall patterns. These varieties require a shorter growing period, allowing farmers to harvest crops before prolonged dry spells or extreme weather events can affect them.

3.3. Agroforestry and Mixed Farming Systems

Agroforestry, the practice of integrating trees into agricultural systems, offers several benefits in arid regions. Trees provide shade for crops, reducing heat stress and preserving soil moisture. Their root systems also help to prevent soil erosion and improve soil fertility by returning organic matter to the soil. This can be particularly important in arid areas where soil degradation and desertification are prevalent.

In addition to agroforestry, **mixed farming systems**, which combine crop cultivation with livestock farming, can help farmers diversify their sources of income and reduce risk. Livestock can provide an alternative source of food and income in times of crop failure, and manure can improve soil fertility, supporting more sustainable farming practices.

3.4. Soil Conservation and Fertility Management

Maintaining and improving soil health is crucial in arid regions, where soil degradation can be accelerated by water scarcity, high evaporation, and extreme weather events. **Soil conservation techniques** such as **contour plowing**, **terracing**, and **mulching** can help reduce soil erosion, retain moisture, and improve soil structure. Mulching, for instance, reduces evaporation, keeps soil temperatures stable, and prevents the soil from drying out.

Organic soil amendments, including compost, cover crops, and animal manure, can also enhance soil fertility. By improving the organic content and water-holding capacity of the soil, these practices can make agricultural systems more resilient to climate stress and increase productivity in arid areas.

3.5. Climate-Smart Agriculture (CSA)

Climate-smart agriculture (CSA) refers to an integrated approach to farming that aims to increase agricultural productivity sustainably while adapting to climate change and reducing greenhouse gas emissions. CSA focuses on three main pillars:

- **Productivity**: Ensuring that agricultural systems remain productive despite changing climate conditions.

- **Adaptation**: Implementing practices that help farmers cope with the impacts of climate change, such as soil management, water conservation, and crop diversification.
- **Mitigation**: Reducing greenhouse gas emissions from agriculture through practices like agroforestry, improved livestock management, and low-emission farming technologies.

CSA promotes the use of technologies and practices that support sustainable land management, water conservation, and the reduction of emissions, helping to build resilience in the face of climate change.

3.6. Climate Information Services and Early Warning Systems

Access to accurate **climate information** and **early warning systems** is critical for farmers in arid regions to make informed decisions about planting, harvesting, and water management. Weather forecasts, drought predictions, and seasonal climate information can help farmers plan their activities and reduce the risks of crop failure.

Early warning systems that alert farmers to potential extreme weather events, such as droughts or floods, enable them to take preventive actions. For example, farmers can delay planting if a dry season is expected or prepare for storms by reinforcing infrastructure or securing harvests. These systems empower farmers to respond proactively to changing climatic conditions and protect their livelihoods.

3.7. Sustainable Livestock Management

In arid regions, livestock farming plays an important role in the economy, but it is highly vulnerable to climate change. **Sustainable livestock management** practices, such as improving grazing techniques, can help mitigate the effects of drought and desertification. **Rotational grazing**, where livestock are moved between different grazing areas, can prevent overgrazing and allow pastures to regenerate.

Additionally, **improved breeds** of livestock that are more resistant to heat stress and diseases common in arid regions can help maintain livestock productivity under changing climatic

conditions. Integrating these practices into farming systems ensures that livestock farming remains viable even as the climate becomes more unpredictable.

3.8. Diversification of Livelihoods

Livelihood diversification is a critical strategy for farmers in arid regions, as it reduces reliance on a single source of income. By engaging in alternative activities, such as **beekeeping**, **fisheries**, or **agro-processing**, farmers can reduce their vulnerability to climate-related risks.

For example, farmers can diversify into **horticulture** (growing fruits and vegetables) that require less water than traditional crops or focus on producing **value-added products** (such as dried fruits or processed foods) to increase income. These alternative livelihoods provide economic stability during times of crop failure or adverse climate conditions.

3.9. Improved Policy and Institutional Support

Government policies and institutional frameworks play a critical role in supporting adaptation strategies in arid regions. Governments must invest in water management infrastructure, such as reservoirs and water recycling systems, to ensure that water resources are used efficiently. Additionally, financial support, such as subsidies for drought-resistant crops or insurance schemes for farmers, can help reduce the economic risks associated with climate change. The World Bank (2019) emphasizes the importance of integrating climate change considerations into national agricultural policies, particularly in regions that are most vulnerable to its impacts. Effective government policies and institutional support are essential for successful adaptation in arid regions. **Subsidies for water-efficient technologies**, **financial support for climate-resilient crops**, and **insurance programs** for farmers can help reduce the economic risks associated with climate change. Additionally, **capacity-building programs** can help farmers access knowledge and resources to implement sustainable practices.

Governments can also invest in **infrastructure** such as water storage systems, irrigation systems, and transportation networks to ensure that farmers are better equipped to deal with

climate variability. International cooperation and financial assistance can also play a key role in supporting adaptation strategies in arid regions.

Adaptation strategies are vital to ensure the resilience of agriculture in arid regions facing the challenges of climate change. By implementing water-efficient irrigation systems, adopting drought-resistant crops, and utilizing sustainable land and livestock management practices, farmers can better cope with the changing climate. Furthermore, improved climate information services, livelihood diversification, and government support play a critical role in helping farmers navigate these challenges. Ultimately, a combination of local knowledge, technological innovation, and effective policy measures will be essential to securing the future of agriculture in arid regions.

4. Mitigation Strategies

In addition to adaptation, mitigation strategies are also necessary to address the long-term impacts of climate change on agricultural productivity in arid regions. Mitigation involves reducing greenhouse gas emissions and promoting practices that enhance carbon sequestration in the soil. One promising approach is the promotion of sustainable land management practices, such as no-till farming, which helps to reduce soil degradation, increase soil carbon storage, and improve water retention (Rattan et al., 2020).

Moreover, the development of renewable energy sources, such as solar power, can help reduce the reliance on fossil fuels for irrigation and other agricultural activities. Solar-powered irrigation systems, for instance, offer an efficient and sustainable alternative to traditional energy-intensive methods (Nhamo et al., 2019).

Mitigation strategies aim to reduce the causes of climate change, primarily by decreasing greenhouse gas (GHG) emissions or enhancing carbon sequestration. In the context of agriculture, mitigation strategies focus on changing farming practices to reduce carbon footprints, improve resource efficiency, and promote sustainable land management. In arid regions, where climate change has a particularly pronounced impact on agricultural productivity, mitigation strategies are critical to safeguard food security and minimize the

adverse effects of climate change. Below are several key mitigation strategies applicable to agriculture in arid regions:

4.1. Sustainable Land Management Practices

Sustainable land management (SLM) practices play a key role in mitigating climate change by enhancing soil health, preventing soil degradation, and increasing the land's ability to store carbon. In arid regions, where soil erosion and desertification are significant concerns, adopting SLM practices is crucial.

- **No-till farming**: This technique involves planting crops without disturbing the soil through plowing or tilling. No-till farming helps preserve soil structure, reduce soil erosion, and increase carbon storage in the soil. By keeping the soil intact, it retains moisture better and improves its overall fertility, which can boost agricultural productivity.
- **Agroforestry**: Integrating trees into agricultural systems through agroforestry can mitigate climate change by sequestering carbon in tree biomass and soil. Trees also help reduce wind and water erosion, improve soil fertility, and provide shade for crops and livestock, thereby lowering heat stress and conserving water.
- **Conservation tillage and crop rotation**: These practices reduce soil disturbance, improve soil health, and enhance carbon sequestration in the soil. Crop rotation can also improve biodiversity, reduce pest pressure, and break disease cycles, contributing to more resilient farming systems.

4.2. Improving Water Use Efficiency

Water scarcity is one of the most significant challenges in arid regions, and climate change is exacerbating this issue. By improving water-use efficiency, agricultural systems can reduce their environmental footprint while adapting to water stress.

- **Drip irrigation**: Drip irrigation delivers water directly to the roots of plants, minimizing evaporation and runoff. This water-efficient technology reduces water consumption,

enhances crop yields, and minimizes the carbon footprint associated with irrigation practices.

- **Rainwater harvesting**: Collecting and storing rainwater during wet periods can provide a supplemental water source during dry spells. Implementing rainwater harvesting systems can help alleviate pressure on groundwater reserves and reduce the need for energy-intensive water pumping systems.

- **Water-efficient crops**: Planting drought-resistant or water-efficient crop varieties reduces the amount of water required for irrigation, conserving both water resources and energy. For example, crops such as millet, sorghum, and certain drought-tolerant wheat varieties are better suited to arid conditions and can maintain yields with limited water input.

4.3. Soil Carbon Sequestration

Agricultural soils are significant carbon sinks, and improving soil carbon storage can be a highly effective mitigation strategy. Practices that increase organic matter in the soil help capture and store carbon, reducing the concentration of greenhouse gases in the atmosphere.

- **Organic farming**: By avoiding synthetic fertilizers and pesticides, organic farming encourages the use of compost, cover crops, and crop residues, which enhance soil organic matter and increase carbon sequestration. These practices also improve soil health, increase water retention, and reduce the need for irrigation.

- **Cover cropping**: Growing cover crops such as legumes, grasses, or other plants between main crop cycles can prevent soil erosion, improve soil fertility, and enhance carbon storage. These crops also protect the soil from the impact of wind and water, which is particularly important in arid regions.

- **Biochar**: Biochar is a form of charcoal produced by heating organic material in the absence of oxygen (a process called pyrolysis). When added to soil, biochar can increase

soil fertility, retain moisture, and store carbon for centuries, making it an effective long-term strategy for carbon sequestration in arid areas.

4.4. Livestock Management and Methane Reduction

Livestock production is a major source of methane (a potent greenhouse gas), especially from ruminants such as cattle, sheep, and goats. In arid regions where livestock farming is common, reducing methane emissions is a key component of climate change mitigation.

- **Improved livestock diets**: Modifying the diet of livestock can reduce methane emissions by improving the efficiency of digestion. Including more high-quality forages and grains in the diet can help livestock digest food more efficiently, reducing the amount of methane produced during digestion.
- **Enteric fermentation management**: Technologies such as **feed additives** (e.g., fats, tannins, and seaweed) can reduce methane production during enteric fermentation in ruminant livestock. This, in turn, reduces overall greenhouse gas emissions associated with livestock farming.
- **Manure management**: Proper manure management can also mitigate methane emissions. **Aerobic composting** and the use of **biogas digesters** to capture methane from manure are effective ways to reduce emissions and use methane as a renewable energy source for farming operations.

4.5. Renewable Energy for Agricultural Operations

The use of renewable energy sources, such as solar and wind power, can significantly reduce the carbon footprint of agricultural operations. In arid regions, where sunlight is abundant, solar energy can be harnessed to power irrigation systems, water pumps, and even greenhouses.

- **Solar-powered irrigation systems**: These systems use solar panels to pump water for irrigation, reducing the reliance on fossil fuels and lowering energy costs for farmers.

Solar-powered water pumps can help alleviate water scarcity by making irrigation more efficient and sustainable.

- **Wind energy**: In regions with strong winds, wind turbines can be used to generate electricity for agricultural operations, reducing dependence on non-renewable energy sources and decreasing greenhouse gas emissions.

4.6. Reducing Fertilizer and Pesticide Use

The use of synthetic fertilizers and pesticides contributes to greenhouse gas emissions, particularly nitrous oxide, which is a potent greenhouse gas. Reducing the use of chemical inputs and adopting more sustainable farming practices can mitigate emissions.

- **Integrated pest management (IPM)**: IPM uses a combination of biological control, crop rotation, and minimal pesticide use to manage pests effectively, reducing the need for chemical pesticides. By reducing pesticide use, IPM lowers the environmental impact and prevents the buildup of harmful chemicals in the ecosystem.

- **Precision agriculture**: Precision farming technologies, such as GPS and remote sensing, allow for more efficient use of fertilizers and pesticides. By applying the correct amount of inputs only where needed, precision agriculture reduces waste and minimizes environmental damage, leading to a decrease in emissions associated with farming.

4.7. Restoration of Degraded Lands

Restoring degraded lands through reforestation, afforestation, and sustainable land management practices can increase carbon sequestration and reduce land degradation in arid regions. **Reforestation** (planting trees in deforested areas) and **afforestation** (planting trees in previously non-forested areas) enhance carbon storage and biodiversity while protecting soil and water resources.

Additionally, **soil restoration** techniques such as reintroducing organic matter, planting deep-rooted plants, and controlling erosion can reverse the effects of desertification and reduce greenhouse gas emissions from degraded land.

Mitigation strategies for agriculture in arid regions focus on reducing greenhouse gas emissions, enhancing carbon storage in soils, and promoting sustainable agricultural practices. Key approaches include adopting water-efficient irrigation systems, improving livestock management, sequestering carbon through soil management practices, and utilizing renewable energy sources. By implementing these strategies, agricultural systems in arid regions can contribute to global climate change mitigation efforts while also increasing resilience to the impacts of climate change. The integration of these practices requires coordinated efforts from farmers, governments, and international organizations to ensure the long-term sustainability of agriculture in arid environments.

5. Conclusion

Climate change poses a significant threat to agricultural productivity in arid regions, where water scarcity, temperature increases, and altered precipitation patterns already challenge farmers. The direct and indirect impacts of climate change, such as reduced crop yields, water shortages, and economic instability, require urgent attention. Adaptation and mitigation strategies, including the use of climate-smart agriculture, efficient water management, and sustainable land practices, are essential for ensuring food security and the long-term viability of agriculture in these vulnerable regions. Furthermore, government support and policy frameworks are crucial for empowering farmers to cope with the changing climate. Addressing these challenges will require global cooperation, innovation, and the commitment to sustainable agricultural practices to safeguard the future of arid regions.

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