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Over View

The Saharan Desert: Climate, Terrain and Contemporary Perspectives

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Abstract: The Sahara Desert, the largest hot desert on earth, represents a complex system shaped by geological evolution, atmospheric circulation and human interactions. This review synthesizes available knowledge on its origin, climate, geomorphology, hydrology, soils, vegetation and socio-economic conditions, with emphasis on recent environmental changes. Geological evidence suggests that aridity in North Africa dates back to the Miocene, with pronounced humid-arid oscillations during the Quaternary driven by orbital forcing and monsoonal variability. The region is characterized by extremely low rainfall, high temperature variability and dominance of aeolian processes. Despite limited water availability, fossil aquifers and external river systems support sparse populations and localized agriculture. Emerging challenges include climate change, desertification, groundwater depletion and socio-economic transitions. Future projections indicate regionally variable responses, highlighting the need for integrated management strategies.

Key words: Sahara Desert, aridity, climate variability, agriculture, groundwater, desertification.

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The Sahara Desert covers approximately 9.2 million km² across North Africa and is the largest hot desert in the world. It extends about 4,500-5,500 km from west to east and 1,500-2,000 km from north to south, encompassing Algeria, Chad, Egypt, Libya, Mali, Mauritania, Morocco, Niger, Sudan, Tunisia and Western Sahara. Although presently characterized by hyper-arid conditions and sparse population, the Sahara has undergone substantial climatic variability over geological time, alternating between humid and arid phases (Kröpelin *et al*., 2008). These fluctuations have shaped its geomorphology, hydrology, ecosystems and patterns of human settlement.

Geological evolution and age: The origin of the Sahara Desert has been widely debated. Earlier studies placed its development in the late Pliocene to early Pleistocene (~2-3 million years ago), whereas more recent evidence suggests that arid conditions in North Africa may date back to the Miocene (Schuster *et al*., 2006). The presence of ~7-million-year-old aeolian deposits in northern Chad supports this earlier origin. During the Quaternary, the Sahara experienced repeated humid-arid cycles driven largely by orbital variations affecting solar radiation and monsoonal circulation. These cycles led to periodic expansion and contraction of desert conditions, influencing vegetation, hydrology and human occupation (Kröpelin *et al*., 2008).

Climate: The Sahara lies between 15° and 35°N latitude and is dominated by subtropical high-pressure systems associated with the descending limb of the Hadley circulation. This results in persistent atmospheric stability and extremely low precipitation, with mean annual rainfall generally below 100 mm (Nicholson, 2013). Temperatures are extreme, with daytime values often exceeding 40°C and marked diurnal variation, while nighttime temperatures may approach freezing during winter. Coastal areas experience moderated conditions due to the Canary Current. High evapotranspiration rates far exceed precipitation, reinforcing the hyper-arid environment.

Climatic variability and recent changes: Paleoclimatic records indicate considerable variability in Saharan climate. During the Last Glacial Maximum (~23,000-16,000 years BP), aridity intensified and dune systems expanded (Rognon, 1976), whereas the African Humid Period (~11,000-5,000 years BP) was characterized by increased rainfall, vegetation expansion and the presence of lakes and rivers (Kröpelin *et al*., 2008). These variations were primarily driven by orbital forcing, which influenced the position of the Intertropical Convergence Zone and the strength of the African monsoon. Reduced dust emissions during humid phases further indicate enhanced vegetation and precipitation (Zhou *et al*., 2023; Palchan and Torfstein, 2019).

In recent decades, the climate of the Sahara and Sahel has been shaped by severe droughts during the 1970s and 1980s, followed by complex precipitation changes. Sea surface temperature anomalies played a major role in these droughts, while partial recovery in rainfall has been accompanied by increased variability and intensity (Biasutti, 2019). An abrupt shift towards a "drought recovery" phase has been reported around the end of the 20th century, associated with warming of tropical and extratropical oceans and enhanced monsoonal moisture (Sindikubwabo *et al*., 2018). Recent decades have also witnessed rising temperatures, increased rainfall variability and more frequent extreme events across the Sahara and its margins (Nicholson, 2013). Desertification remains a major concern, particularly in the Sahel region. The Sahara is also a major global source of atmospheric dust, influencing climate systems and nutrient cycles. Future projections indicate complex and regionally variable responses, including both potential increases in rainfall and intensification of aridity (Zhou *et al*., 2023).

Physiography and landforms: The Sahara exhibits diverse geomorphic features dominated by aeolian processes. Sand seas (ergs) cover about 25% of the region, while gravel plains (regs) account for nearly 70% (Cooke *et al*., 1993; Goudie, 2018). Other features include rocky plateaus (hamadas), saline depressions (chotts) and dry valleys (wadis). Dune types include barchans, transverse, longitudinal and star dunes, with heights reaching up to 300 m. Mountain ranges such as the Tibesti and Ahaggar massifs represent major volcanic uplifts influencing local geomorphology and hydrology (Goudie, 2018).

Hydrology: Water availability in the Sahara is extremely limited. Surface water depends largely on rivers originating outside the desert, notably the Nile and Niger. Wadis represent ephemeral drainage systems formed during wetter periods. Lake Chad has undergone substantial shrinkage due to reduced inflow, high evaporation and increasing human water use (World Bank, 2016). Groundwater resources, particularly fossil aquifers such as the Nubian Sandstone Aquifer System, are critical for sustaining human activities but have very low recharge rates (UNEP, 2006).

The extreme scarcity of surface water is forcing Sahara towards a heavy reliance on vast, non-renewable fossil aquifers such as the Nubian Sandstone Aquifer System and the North Saharan Septentrional Basin (UNEP, 2006). These underground reservoirs, largely charged during the humid periods of the Quaternary, contain immense volumes of freshwater but receive negligible contemporary recharge under current hyper-arid conditions. As population growth and agricultural transformation accelerate, the intensive extraction of this "fossil water" has led to significant groundwater depletion and a decline in artesian pressure (World Bank, 2016). This drawdown not only threatens the long-term viability of modern irrigation projects but also jeopardizes traditional oasis ecosystems that depend on natural spring discharges. The increasing depth of the water table necessitates more energy-intensive pumping, further complicating the socio-economic stability of regions already vulnerable to climate-driven land degradation and food insecurity (Lombe *et al*., 2024; **Abeldaño Zuñiga** *et al*., 2021).

Soils and vegetation: Saharan soils are poorly developed, with low organic matter and weak horizon differentiation. Salinity is common in depressions and biological activity is limited (Goudie, 2018). Vegetation is sparse and adapted to arid conditions, occurring mainly in highlands, wadis and oases. Dominant species include drought-tolerant grasses, shrubs such as *Acacia* and *Artemisia*, and halophytes such as *Tamarix*, exhibiting adaptations like deep root systems and reduced transpiration (Cooke *et al*., 1993).

Human settlement and livelihoods: The Sahara supports a population of approximately 2.5 to 4 million people. Settlements are closely linked to water availability, particularly in oasis regions and along rivers. Traditional livelihoods include pastoralism, oasis agriculture and trade. Ethnic groups such as the Berbers, Tuareg and Toubou have historically adapted to the desert environment through mobility and efficient resource use. But demographic changes are now taking place very swiftly (UNEP, 2006) characterized by a "youth bulge," with over 50% of the population under the age of 20 in many countries (Rabier *et al*., 2026). This creates immediate pressure on the socio-economic and environmental frameworks. Nine countries in the region, including Niger and Chad, are projected to double in population size by 2054 (World Population Prospects 2024). This growth is a primary driver of population displacement as traditional land-use systems fail to meet the rising demand for food and fuel (Abeldaño Zuñiga *et al*., 2021). Many of these countries also face severe infrastructure deficits. For example, only about 32% of people in Guinea can read or write, and in Niger, despite mineral wealth, poverty remains pervasive due to high dependency ratios and environmental stressors (World Population Review, 2026).

Economic development: Economic activities in the Sahara include oil and mineral extraction, limited agriculture and emerging renewable energy initiatives. While resource extraction has contributed to infrastructure development, its benefits remain unevenly distributed. Solar energy offers significant potential due to high irradiance; however, constraints related to cost, infrastructure and environmental considerations limit large-scale implementation.

The agricultural transformation of the Saharan arid zone: The entire continent of Africa from north to south presents a critical, progressive environmental transition among three distinct eco-systems; the Sahara (a vast hyper-arid desert zone), the Sahel (a semi-arid climatic zone) and the Savanna (a more humid climate with a mix of trees, shrubs, and grasses). Each of these regions is known for uniqueness in terms of extremes of climate, aeolian landforms, vegetation degradation and land restoration. Agricultural transformation has taken routes as per above climatic and physiographic transitions. Important land and water bodies like the Atlantic Ocean, the Atlas Mountains, the Mediterranean Sea, the Red Sea, and the Sahel region and occurrences of 20 saline lakes in the Sahara Desert and Lake Chad (freshwater) have impacted the climatic and agrarian landscape of this region. At present, the agricultural landscape of the Sahara is undergoing a profound structural transformation, primarily driven by the transition from traditional surface-water reliance to the intensive exploitation of deep fossil aquifers. Historically, Saharan agriculture was geographically constrained to natural oases and the floodplains of external river systems like the Nile and Niger. In these traditional settings, ethnic groups such as the Tuareg and Berbers adapted to hyper-arid conditions through mobility and resource management, utilizing gravity-based irrigation to sustain limited crops. However, modern technological interventions have shifted the focus toward massive sedimentary basins, such as the Nubian Sandstone Aquifer System, enabling the "greening" of hyper-arid regions through industrial-scale irrigation despite extremely low contemporary recharge rates.

This shift toward groundwater-dependent cultivation is largely a strategic response to the extreme climate volatility and severe droughts that defined the region in the late 20th century. Sea surface temperature anomalies were the primary driver of the devastating droughts that struck the region in the 1970s and 1980s. While seasonal rainfall totals have partially recovered in recent decades, the characteristics of the rainy seasons have fundamentally changed, resulting in precipitation that is now more intermittent and intense (Biasutti, 2019). Meteorological droughts across Africa continue to pose a significant threat to agricultural stability, which remains heavily reliant on hydro-climatic consistency (Ayugi *et al*., 2022). By tapping into fossil water reserves, agricultural systems can buffer against the effects of erratic rainfall and prolonged dry seasons that historically led to massive declines in the productivity and quality of staples like millet, sorghum, and peanuts (Ayugi *et al*., 2022).

Despite these advancements, the reliance on underground water introduces significant long-term environmental and socio-economic constraints. Most Saharan groundwater resources are non-renewable fossil aquifers. Intensive extraction for large-scale agriculture is leading to rapid depletion, while the irrigation of poorly developed Saharan soils often results in high salinity and land degradation (Goudie, 2018). In Sub-Saharan and neighbouring regions, erratic rainfall and prolonged dry seasons have accelerated land degradation, dried up water sources, and resulted in severe food insecurity and loss of pasture (Lombe *et al*., 2024). These environmental stressors, compounded by climate change, have become fundamental push factors for socio-economic instability and large-scale population displacement across the continent (Abeldaño Zuñiga *et al*., 2021). While the transition to groundwater-based systems has improved immediate food security, the long-term sustainability of the Sahara depends on integrated management strategies that balance resource extraction with the fragile ecological limits of the desert. Agricultural productivity in these nations is currently estimated to be 35% below its potential due to climate disruptions such as intermittent rainfall and land degradation (Rabier *et al*., 2026; Ayugi *et al*., 2022).

Agricultural and socio-economic impacts: Climate variability over the past five decades has significantly affected ecological stability and agricultural productivity. Meteorological droughts have caused substantial damage to agriculture, which remains highly dependent on hydro-climatic stability, leading to declines in crop productivity and grain quality, particularly for millet, sorghum and peanuts (Ayugi *et al*., 2022). Increasing frequency and severity of droughts have accelerated land degradation, reduced water availability and intensified food insecurity and pasture loss (Lombe *et al*., 2024). Persistent environmental stressors driven by climate change have also emerged as important drivers of population displacement and migration (Abeldaño Zuñiga *et al*., 2021).

Conclusions

The Sahara Desert is a dynamic system shaped by interactions among geological processes, climatic variability and human activities. Its long history of climatic oscillations highlights its sensitivity to environmental change. Contemporary challenges such as climate change, desertification and resource depletion necessitate integrated and sustainable management strategies. Future research should emphasize interdisciplinary approaches combining climate science, hydrology and socio-economic analysis.

References

Ayugi, B., Eresanya, E.O., Onyango, A.O., Ogou, F.K., Okoro, E.C., Okoye, C.O., Anoruo, C.M., Dike, V.N., Ashiru, O.R., Daramola, M.T., Mumo, R. and Ongoma, V. 2022. Review of meteorological drought in Africa: Historical trends, impacts, mitigation measures, and prospects. *Pure and Applied Geophysics* 179: 1365-1386. https://doi.org/10.1007/s00024-022-02988-z

Biasutti, M. 2019. Rainfall trends in the African Sahel: Characteristics, processes, and causes. *WIREs Climate Change* 10: e591. https://doi.org/10.1002/wcc.591

Cooke, R.U., Warren, A. and Goudie, A.S. 1993. *Desert Geomorphology*. UCL Press, London.

Goudie, A.S. 2018. *Desert Geomorphology* (2nd ed.). Wiley-Blackwell, Oxford. https://doi.org/10.1002/9781119331803

Kröpelin, S., Verschuren, D., Lézine, A.M., Eggermont, H., Cocquyt, C., Francus, P., Benoit, J.P., Quade, J., Uzunidis, A., Engstrom, D.R. and Lausman, F. 2008. Climate-driven ecosystem succession in the Sahara: The past 6000 years. *Science* 320: 765-768. https://doi.org/10.1126/science.1154913

Lombe, P., Carvalho, E. and Rosa-Santos, P. 2024. Drought dynamics in Sub-Saharan Africa: Impacts and adaptation strategies. *Sustainability* 16: 9902. https://doi.org/10.3390/su16229902

Nicholson, S.E. 2013. The West African Sahel rainfall regime and its variability. *ISRN*

Meteorology Article ID 453521. https://doi.org/10.1155/2013/453521

Palchan, D. and Torfstein, A. 2019. A record of Saharan dust supply to the Eastern Mediterranean. *Nature Communications*, 10: 3803. https://doi.org/10.1038/s41467-019-11781-w

Rabier, S., May, J.F. and Bado, A.R. 2026. Sub-Saharan Africa's rapid population growth: Challenges and opportunities. In: *L'économie africaine 2026* (Eds. Serge Rabier and John F. May). La Découverte, Paris.

Rognon, P. 1976. Variations climatiques au Sahara depuis 40,000 ans. *Revue de Géographie Physique et de Géologie Dynamique* 18: 251-282.

Schuster, M., Duringer, P., Ghienne, J.F., Vignaud, P., Mackaye, H.T., Likius, A. and Brunet, M. 2006. The age of the Sahara Desert. *Science* 311: 821. https://doi.org/10.1126/science.1120161

Sindikubwabo, C., Li, R. and Wang, C. 2018. Abrupt change in Sahara precipitation and the associated circulation patterns. *Atmospheric and Climate Sciences* 8: 262-273. https://doi.org/10.4236/acs.2018.82017

UNEP 2006. *Africa Environment Outlook 2*. United Nations Environment Programme, Nairobi.

World Population Prospects 2024: Summary of Results of United Nations Department of Economic and Social Affairs, Population Division. (UN DESA/POP/2024/TR/NO. 9). United Nations, New York.

World Bank 2016. *Lake Chad Basin: Sustainable Development Support*. World Bank, Washington DC. https://doi.org/10.1596/25037

World Population Review 2026. *Africa Population 2026.* Available at: https://worldpopulationreview.com/continents/africa.

Zhou, P., Brovkin, V., Claussen, M. and Lu, Z. 2023. Dust emissions and vegetation feedbacks during the African Humid Period. *Climate of the Past* 19: 2445-2462. https://doi.org/10.5194/cp-19-2445-2023

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