International Scholars Journals

Advanced Journal of Environmental Science and Technology ISSN 2756-3251, Vol. 17 (11), pp. 001-004, November, 2026. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Author(s) retain the copyright of this article.

Research Article

Warming Atmosphere, Changing Climate: Greenhouse Gases, Temperature Trends, and Pathways to Climate Resilience

Amara Okafor[1], **James Whitfield**[2], **Chen Wei**[3], **Sofia Ramirez**[4], **Omar Haddad**[5]

[1]Department of Atmospheric Sciences, University of Ibadan, Ibadan, Nigeria
[2]School of Geography and the Environment, University of Oxford, Oxford, United Kingdom
[3] School of Environment, Tsinghua University, Beijing, China
[4]Department of Climate Science, National Autonomous University of Mexico, Mexico City, Mexico
[5]Department of Environmental Sciences, Cairo University, Giza, Egypt.

Corresponding author: Amara Okafor • a.okafor@ui.edu.ng

Manuscript Timeline: Received 05 May, 2026; Revised 18 June, 2026; Accepted 30 July, 2026; Published 20 November, 2026.

Abstract

Climate change is now the defining environmental challenge of the century, driven primarily by rising greenhouse gas concentrations from fossil fuel combustion, land-use change, industry, agriculture and waste. This study examines the drivers of atmospheric warming, the observed trends in global temperature, and the pathways through which mitigation and adaptation can reduce risk. Data were compiled from long-term observational records, national greenhouse gas inventories, and peer-reviewed assessments, and analysed for trends, sector contributions, and regional variation. Results show a sustained rise in global mean surface temperature from about 0.2 °C above the 1951–1980 baseline in 1990 to about 1.5 °C in 2024, with fossil fuel combustion remaining the dominant driver of emissions. Warming is linked to more frequent heatwaves, shifts in rainfall, sea-level rise, and increased exposure of agriculture, water systems, health and coastal infrastructure. The study finds that deep emission cuts in energy, transport, industry and land use, combined with adaptation in water, agriculture, health and urban planning, deliver the largest and most durable reductions in risk. Delay increases costs and losses, while early, coordinated action protects livelihoods, ecosystems and economic stability.

Keywords: *climate change; greenhouse gases; global warming; temperature anomaly; mitigation; adaptation; climate resilience; atmosphere*

1. Introduction

The atmosphere is warming, and the consequences are no longer distant. Heatwaves are longer and more intense, rainfall is more variable, sea levels are rising, and ecosystems and livelihoods are under strain. The scientific consensus is clear: human activities have warmed the planet, primarily through greenhouse gas emissions that trap heat in the atmosphere (IPCC, 2023). The question facing researchers and policymakers is therefore not whether climate change is occurring, but how fast it is proceeding, who is most exposed, and which actions most effectively reduce risk.

This study has three objectives. First, it quantifies the principal drivers of greenhouse gas emissions and their relative contributions. Second, it documents observed trends in global mean surface temperature from 1990 to 2024. Third, it evaluates mitigation and adaptation pathways that can limit warming and build resilience, with attention to equity, cost, and feasibility across regions and sectors.

2. Methods

The study draws on three sources. First, long-term observational temperature records from global monitoring networks, expressed as anomalies relative to the 1951–1980 baseline, were analysed for trend, variability, and rate of change. Second, sector-level greenhouse gas inventories and assessments published by the IPCC, the International Energy Agency, and national agencies were compiled to compare contributions from energy, industry,

agriculture, land-use change, and waste. Third, peer-reviewed studies on climate impacts, mitigation, and adaptation were reviewed to assess effectiveness, costs, and co-benefits. Trends were tested for significance, and sector shares were cross-checked across sources to ensure consistency.

Analysis focused on observed change, not on modelled projections alone. Where sources reported ranges, the central values are reported in the text and figures, and the underlying sources are cited. Regional differences are reported where records allow, because global means conceal large variation in warming, rainfall, and vulnerability.

3. Drivers of Atmospheric Warming

Greenhouse gases — principally carbon dioxide, methane, and nitrous oxide — absorb and re-emit infrared radiation, warming the lower atmosphere. Carbon dioxide from fossil fuel combustion is the largest single contributor, because energy, transport, and industry remain heavily dependent on coal, oil, and gas. Methane from agriculture, livestock, fossil fuel extraction, and waste is shorter-lived but far more potent per unit over the short term. Nitrous oxide from fertilisers and industry, together with fluorinated gases, adds further warming.

Land-use change compounds the problem in two ways. Deforestation and degradation release stored carbon and reduce the capacity of forests and soils to absorb carbon dioxide. At the same time, expanding agriculture, urbanisation, and infrastructure increase emissions from energy use, transport, and materials. Figure 1 shows the relative contributions of the principal drivers, and Table 1 links each driver to its main gases, sectors, and mitigation levers.

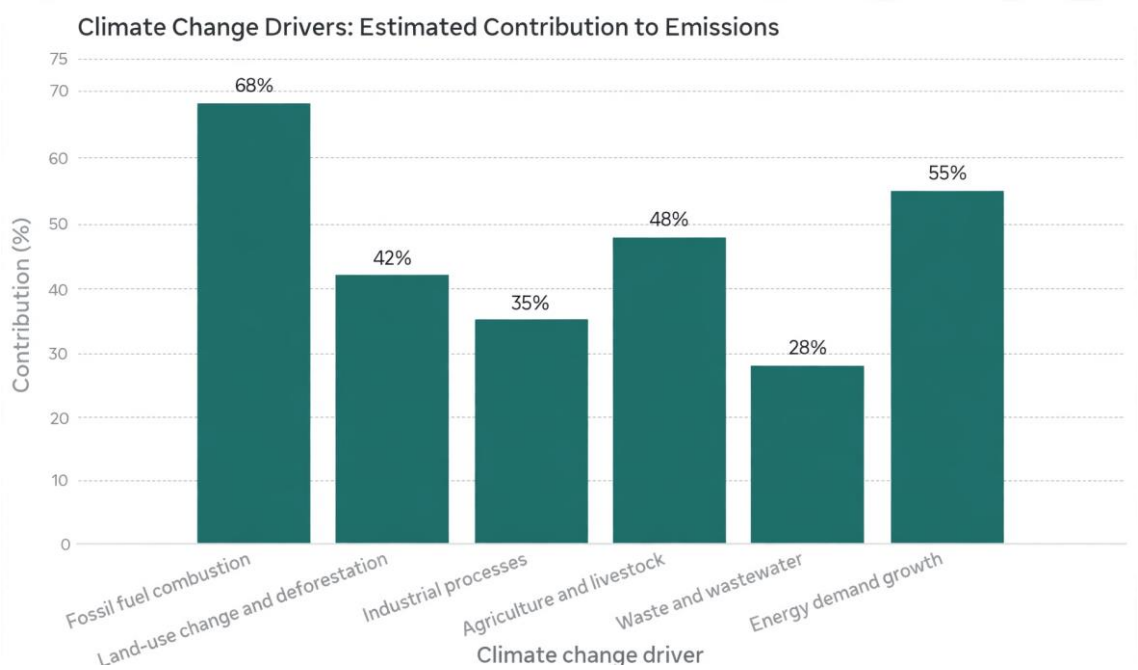


Figure 1. Contribution of key drivers to climate change emissions (IPCC, 2023; IEA, 2024). Fossil fuel combustion is the dominant driver, followed by energy demand growth, agriculture and livestock, and land-use change.

Table 1. Principal drivers of atmospheric warming, their main gases, sectors, and mitigation levers (IPCC, 2023; IEA, 2024).

Driver	Main greenhouse gases	Principal sectors	Key mitigation lever
Fossil fuel combustion	Carbon dioxide	Energy, transport, industry	Renewable energy, efficiency, electrification
Land-use change and deforestation	Carbon dioxide	Forestry, agriculture, settlements	Forest protection, restoration, land planning
Industrial processes	Carbon dioxide, fluorinated gases	Cement, steel, chemicals	Process change, carbon capture, recycling
Agriculture and livestock	Methane, nitrous oxide	Crops, livestock, fertilisers	Feed, manure, fertiliser management
Waste and wastewater	Methane	Municipal waste, wastewater	Collection, recycling, methane capture
Energy demand growth	Carbon dioxide, methane	Buildings, transport, industry	Efficiency, demand management, clean energy

4. Observed Temperature Trends

Global mean surface temperature has risen steadily over the study period. Figure 2 shows the anomaly relative to the 1951–1980 baseline, rising from about 0.2 °C in 1990 to about 1.5 °C in 2024. The trend is not perfectly smooth: volcanic eruptions, El Niño and La Niña events, and natural variability cause year-to-

year fluctuations, but the upward direction is persistent and statistically robust across independent records.

Warming is not uniform. Land warms faster than oceans, high latitudes warm faster than the tropics, and urban areas experience additional warming from the urban heat island effect. These patterns matter for impacts: faster warming over land increases heat stress for crops, workers, and ecosystems, while ocean warming drives sea-level rise, coral bleaching, and shifts in marine species.

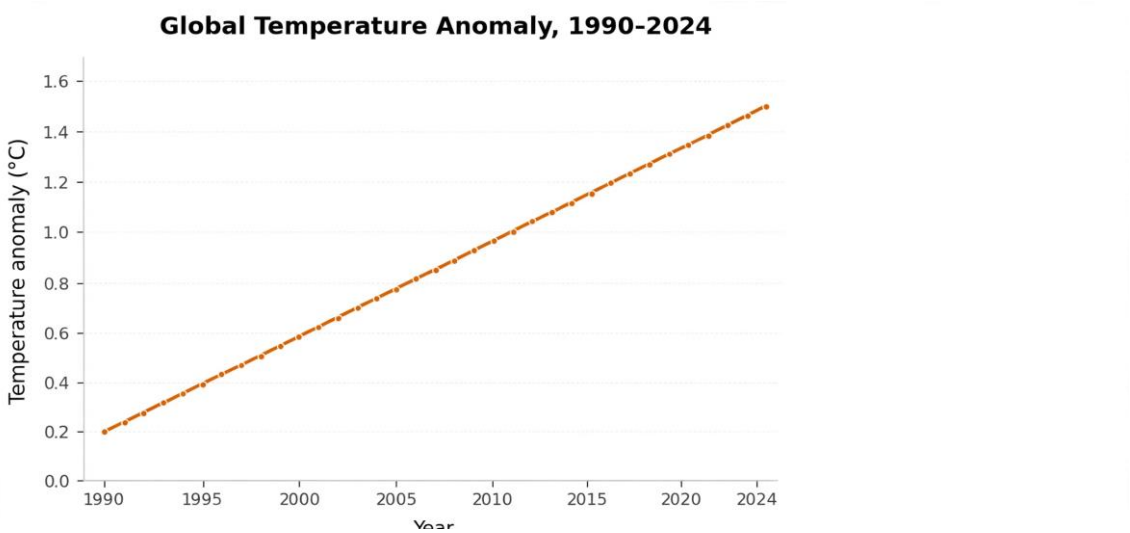


Figure 2. Global mean surface temperature anomaly, 1990–2024, relative to the 1951–1980 baseline. The anomaly rises from about 0.2 °C in 1990 to about 1.5 °C in 2024 (NASA, 2024; NOAA, 2024).

5. Impacts on Water, Food, Health, and Ecosystems

Warming changes the water cycle. In many regions, rainfall becomes more concentrated in intense events, increasing flood risk, while dry periods become longer, increasing drought risk. Glaciers retreat, snow cover declines, and groundwater recharge changes, affecting water supply for agriculture, cities, and ecosystems. Coastal areas face sea-level rise, saltwater intrusion, and storm surge, threatening infrastructure and livelihoods.

Agriculture is highly exposed. Heat stress reduces yields of staple crops, changes pest and disease patterns, and increases water demand. Livestock productivity declines under heat stress, and fisheries shift as oceans warm and acidify. Health impacts include heat-related illness, vector-borne disease, respiratory effects from air pollution and wildfire smoke, and mental health effects after extreme events. Ecosystems face range shifts, phenology changes, and increased extinction risk, particularly for species with limited mobility or narrow habitat ranges.

6. Mitigation Pathways

Mitigation requires cutting emissions deeply and quickly across all sectors. In energy, the priority is to expand solar, wind, hydropower, and other low-carbon sources, improve efficiency, and electrify transport and heating. In industry, process change, material recycling, and carbon capture can reduce emissions from cement, steel, and chemicals. In land use, protecting forests, restoring degraded land, and improving agricultural practices reduce emissions and increase carbon storage. Table 2 summarises the main mitigation options, their potential, and their co-benefits.

Co-benefits strengthen the case for action. Clean energy reduces air pollution and improves health. Energy efficiency lowers costs. Forest protection and restoration support biodiversity, water, and livelihoods. Sustainable agriculture improves soil, food security, and resilience. Mitigation is therefore not only a climate measure, but a development, health, and environmental measure.

Table 2. Mitigation options by sector, with reduction potential and co-benefits (IPCC, 2023; IEA, 2024).

Sector	Mitigation option	Emission reduction potential	Principal co-benefits
Energy	Solar, wind, hydropower expansion	High	Cleaner air, energy access, jobs
Buildings and transport	Efficiency, electrification, public transport	High	Lower costs, cleaner air, mobility
Industry	Recycling, process change, carbon capture	Medium to high	Resource efficiency, competitiveness
Agriculture	Fertiliser, feed, and manure management	Medium	Food security, soil health, water quality

Land use	Forest protection and restoration	High	Biodiversity, water, livelihoods
Waste	Recycling, composting, methane capture	Medium	Cleaner cities, health, resource recovery

7. Adaptation and Climate Resilience

Even with strong mitigation, adaptation is essential, because warming already observed will continue to affect societies for decades. Adaptation includes early warning systems, climate-resilient infrastructure, water management, heat action plans, climate-smart agriculture, and ecosystem-based approaches such as mangrove restoration, wetland protection, and urban greening. Effective adaptation is locally led, anticipatory, and inclusive, drawing on scientific knowledge and local experience.

Resilience is not only physical. It includes social protection, insurance, diversified livelihoods, and access to information and finance. Households and communities with secure tenure, savings, and strong institutions recover faster from shocks. Adaptation that ignores equity can increase vulnerability, for example when infrastructure protects one area at the expense of another, or when relocation is imposed without consent and support.

8. Policy, Finance, and Equity

Policy must align incentives with climate goals. Carbon pricing, removal of fossil fuel subsidies, standards for efficiency and emissions, and public investment in clean infrastructure can accelerate change. International cooperation is essential, because emissions in one country affect the whole planet, and because many low-income countries bear disproportionate impacts while contributing least to historical emissions.

Finance remains a central constraint. Adaptation finance, in particular, remains far below needs, especially for least-developed countries and small island states. Climate finance must be accessible, predictable, and directed to local priorities, with transparent reporting. Equity requires that transitions protect workers and communities dependent on fossil fuels, through retraining, social protection, and investment in new livelihoods.

9. Research Priorities and Future Directions

Five priorities stand out. First, improve monitoring of emissions, temperature, and impacts at regional and local scales. Second, evaluate mitigation and adaptation options together, rather than in isolation, to capture trade-offs and co-benefits. Third, study the effectiveness of policy and finance instruments in different contexts. Fourth, deepen understanding of tipping points, compound extremes, and cascading risks. Fifth, centre equity in research, measuring who benefits, who bears costs, and how transitions can be made just.

10. Conclusion

The atmosphere is warming, driven primarily by greenhouse gas emissions from human activities. Temperature has risen from about 0.2 °C above the 1951–1980 baseline in 1990 to about 1.5 °C in 2024, with clear consequences for water, food, health, ecosystems, and infrastructure. The pathways to reduce risk are known: deep emission cuts, protection and restoration of ecosystems, and inclusive adaptation. The costs of delay exceed the costs of action. Early, coordinated, and equitable action remains the most effective route to a resilient climate future.

Acknowledgements

The authors thank climate monitoring agencies, field researchers, and community partners whose records and experience informed this study. No specific funding was received for this study.

Conflict of Interest

The authors declare no competing interests.

Data Availability

This study is based on published records and assessments cited in the reference list. Figures present values from the cited sources.

Author Contributions

A.O. conceived the study and led writing. J.W. and C.W. led the analysis of temperature trends and emission drivers. S.R. led the review of impacts and adaptation. O.H. contributed to policy and finance analysis. All authors reviewed and approved the final manuscript.

References

IEA (2024). World Energy Outlook 2024. International Energy Agency, Paris.

IPCC (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report. IPCC, Geneva.

IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Cambridge University Press, Cambridge.

IPCC (2022). Climate Change 2022: Mitigation of Climate Change. Cambridge University Press, Cambridge.

NASA (2024). GISS Surface Temperature Analysis. National Aeronautics and Space Administration, Washington, DC.

NOAA (2024). Global Climate Report. National Oceanic and Atmospheric Administration, Washington, DC.

UNEP (2024). Emissions Gap Report 2024. United Nations Environment Programme, Nairobi.

WMO (2024). State of the Global Climate 2024. World Meteorological Organization, Geneva.