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Climate change: Causes, impacts, and pathways toward sustainability

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Abstract. Climate change has emerged as the most pressing environmental, economic, and social challenge of the 21st century. Driven largely by anthropogenic greenhouse gas emissions, it is accelerating global warming, altering weather patterns, and intensifying natural disasters. This paper reviews the scientific basis of climate change, examines its ecological and socio-economic impacts, and evaluates strategies for mitigation and adaptation. The findings highlight that climate change is not only an environmental issue but also a multidimensional crisis that requires coordinated global action, technological innovation, and behavioral change. The United Arab Emirates (UAE) and the wider Middle East and North Africa (MENA) region face unique vulnerabilities: extreme heat, water scarcity, and reliance on fossil fuels. However, the UAE is also emerging as a hub for climate innovation, hosting COP 28 in 2023 and investing in renewable energy, carbon capture, and sustainable agriculture. The Earth's climate system has always fluctuated, but the rate of change observed in the last century is unprecedented. This paper seeks to: identify the major drivers of climate change, analyze its environmental, social, and economic impacts, and explore mitigation and adaptation strategies to promote sustainability.

Introduction

The Earth's climate system has always fluctuated, but the rate of change observed in the last century is unprecedented. According to the Intergovernmental Panel on Climate Change (IPCC), average global surface temperatures have already increased by approximately 1.1°C above pre-industrial levels, with profound consequences for ecosystems, economies, and societies. Rising sea levels, melting glaciers, and extreme weather events are reshaping the natural and human environment.

Causes of Climate Change: climate change is driven by both natural and anthropogenic factors, though human activity is the dominant force in the present era.

- ✓ Greenhouse Gas Emissions: Burning of fossil fuels for energy, transportation, and industry releases large amounts of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).
- ✓ Deforestation: Removal of forests reduces carbon sequestration capacity, intensifying atmospheric CO_2 buildup.
- ✓ Industrial Agriculture: Livestock farming and fertilizer use contribute significant CH_4 and N_2O emissions.
- ✓ Urbanization: Expanding cities and infrastructure increase energy demand, waste generation, and heat island effects.

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Impacts of Climate Change

Environmental Impacts

- ✓ Rising Sea Levels: Melting ice sheets and thermal expansion of oceans threaten low-lying coastal regions.
- ✓ Loss of Biodiversity: Species extinction rates are accelerating due to habitat loss, shifting climates, and ocean acidification.
- ✓ Extreme Weather: Heatwaves, floods, and hurricanes are becoming more frequent and intense.

Socio-Economic Impacts

- ✓ Food Security: Crop yields are declining in vulnerable regions due to droughts, pests, and shifting rainfall.
- ✓ Public Health: Increased prevalence of heat stress, respiratory diseases, and vector-borne illnesses.
- ✓ Economic Disruptions: Infrastructure damage from climate disasters, rising energy costs, and loss of livelihoods.
- ✓ Climate Refugees: Displacement of populations due to sea-level rise, desertification, and resource scarcity.

Mitigation Strategies

- ✓ Renewable Energy Transition: Scaling up solar, wind, hydro, and geothermal power to reduce fossil fuel reliance.
- ✓ Energy Efficiency: Enhancing building design, transportation systems, and industrial processes.
- ✓ Carbon Sequestration: Expanding reforestation and exploring carbon capture, utilization, and storage (CCUS).
- ✓ Green Chemistry: Designing safer chemicals and sustainable materials to reduce environmental hazards.

Adaptation Strategies

- ✓ Climate-Resilient Infrastructure: Building flood defenses, drought-resistant crops, and sustainable cities.
- ✓ Water Resource Management: Efficient irrigation, desalination powered by renewables, and wastewater recycling.
- ✓ Policy and Governance: Integrating climate risks into national planning and international cooperation (e.g., Paris Agreement).
- ✓ Community Engagement: Promoting awareness, sustainable practices, and local innovation.

Case Study

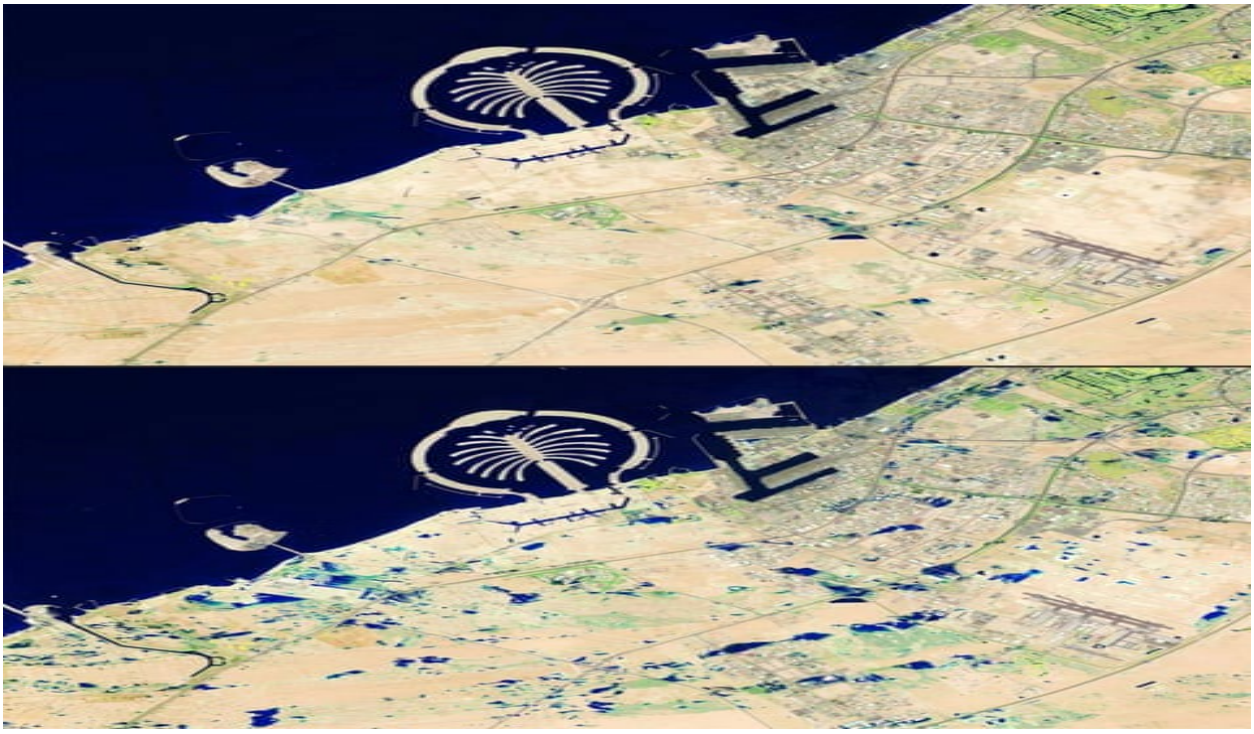
In April 2024, the UAE suffered its heaviest rainfall in 75 years, resulting in severe flooding across multiple emirates.



Dubai experienced over 14 cm of rainfall within a 24-hour period, an amount comparable to one and a half years of its typical average precipitation. This was the heaviest downpour since records began in 1949. Widespread flooding across the UAE and Oman resulted in extensive damage to infrastructure and vehicles, accompanied by power outages and the suspension of educational activities. The study found that fossil fuels and concrete combined to worsen the "death trap" conditions during recent record flooding in the United Arab Emirates and Oman. According to the World Weather Attribution team, rainfall events during El Niño years, such as the recent episode, have intensified by 10–40% in the region due to anthropogenic climate disruption. The absence of adequate natural drainage systems further contributed to the rapid inundation of roadways. The extreme rainfall of 16–17 April resulted in severe flooding across parts of the Arabian Peninsula, claiming at least 23 lives, including 10 children who perished when their school bus was swept away. More than 1,000 flights were cancelled, causing several days of delays, after the runway was flooded at Dubai airport, the world's busiest international airport. In the immediate aftermath of the downpour, there was speculation that artificial weather modification might have been the cause, because the UAE is known to use cloud-seeding technology to alleviate water shortages. However, the new study concluded that "cloud seeding had no significant influence in the event". The UAE's National Center of Meteorology refuted claims of conducting cloud-seeding operations on the day of the heavy rainfall. Nevertheless, anthropogenic factors were found to have exacerbated the event's impacts. Due to limited historical rainfall records, the researchers were unable to quantify the exact contribution of human-induced climate change; however, their analysis indicated that global warming, driven primarily by fossil fuel combustion, was the most probable cause of the unprecedented downpour.

This region of the Persian Gulf is one of the driest places on Earth, but it is historically prone to intense rain and flash flooding every few years, particularly during El-Nino phases. Most scientists believe climate disruption is making El-Nino events more intense, by a factor of 10-40%, in this region. The study notes that a warmer atmosphere can hold more moisture. At the current 1.2 ^{0}C level of global heating above pre-industrial levels, the atmosphere can hold about 8.4% more moisture. Altered circulation dynamics in a warmer and increasingly unstable climate can intensify rainfall events in certain regions.

Human alterations of the landscape have also added to the risks faced by people in low-lying areas. Eight out of 10 people in Oman and the UAE live in flood-prone neighborhoods and many drivers commute through high-risk areas. Despite prior alerts issued by meteorological agencies, a significant number of individuals remained trapped by the flooding.



Nasa has released satellite images that reveal the extent of the flooding in the normally dry desert region. The image shows heavy inundation in industrial areas of Jebel Ali, just south of Dubai port, and near the green resorts and parks south of Palm Jebel Ali, a town 20 miles south-west of the city, which hosted the Cop28 climate summit last year. Parts of Abu Dhabi, the UAE's capital, were also underwater until 19 April.

Friederike Otto, Senior Lecturer in Climate Science at Imperial College London, emphasized the urgent need to end fossil fuel combustion and to reconfigure urban design, highlighting the detrimental impact of excessive concrete use. She noted that the high number of fatalities was largely attributable to the near absence of permeable surfaces, which caused roads to rapidly transform into rivers during the downpour. This builds a death trap.

Summary

The international community confronts a twofold challenge: swiftly curbing greenhouse gas emissions and simultaneously adapting to the climate impacts that are now unavoidable. While scientific and technological solutions exist, barriers such as economic inequality, political resistance, and lack of awareness impede progress. Importantly, climate change is not uniform; developing countries, despite contributing the least, bear the greatest burden of its impacts. Achieving climate justice requires equity in funding, technology transfer, and adaptation measure. Climate change represents one of the most significant challenges confronting contemporary society. It threatens ecosystems, livelihoods, and global stability. Addressing it demands a holistic approach that combines science, policy, innovation, and behavioral change. If the global community acts collectively prioritizing sustainability over short-term gains it is still possible to limit warming, protect ecosystems, and secure a livable future.

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