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CLIMATE CHANGE AND ITS IMPACT ON THE ENVIRONMENT

Abstract : This article examines the causes and consequences of climate change and assesses its environmental impacts. Particular attention is paid to the role of anthropogenic greenhouse gas emissions, land use changes, and industrial activities in accelerating global warming. The study analyzes the impacts of climate change on ecosystems, biodiversity, water resources, soil conditions, and atmospheric processes. Environmental impact assessment methods are discussed as important tools for identifying, monitoring, and assessing climate-related risks.

Keywords: Climate change, global warming, environmental impact assessment, greenhouse gases, ecosystems, biodiversity, ecological sustainability, extreme weather events, adaptation, mitigation, natural resources, environmental monitoring.

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ИЗМЕНЕНИЕ КЛИМАТА И ЕГО ВОЗДЕЙСТВИЕ НА ОКРУЖАЮЩУЮ СРЕДУ

Аннотация. В данной статье рассматриваются причины и последствия изменения климата, а также проводится оценка его воздействия на окружающую среду. Особое внимание уделено роли антропогенных выбросов парниковых газов, изменениям землепользования и промышленной деятельности в ускорении процессов глобального потепления. В исследовании анализируется влияние климатических изменений на экосистемы, биоразнообразие, водные ресурсы, состояние почв и

атмосферные процессы. Методы оценки воздействия на окружающую среду рассматриваются как важные инструменты для выявления, мониторинга и оценки рисков, связанных с изменением климата.

Ключевые слова: изменение климата, глобальное потепление, оценка воздействия на окружающую среду, парниковые газы, экосистемы, биоразнообразие, экологическая устойчивость, экстремальные погодные явления, адаптация, смягчение последствий, природные ресурсы, экологический мониторинг.

Climate change has become one of the most important environmental challenges of the 21st century, affecting natural ecosystems, socio-economic systems and human well-being globally. The rapid increase in anthropogenic greenhouse gas emissions since the Industrial Revolution has significantly altered the Earth's energy balance, resulting in unprecedented changes in atmospheric, oceanic and terrestrial processes. According to the World Meteorological Organization (WMO), 2024 was the warmest year in 175 years of instrumental records, with the global average surface temperature approximately 1.55 ± 0.13°C above the pre-industrial (1850–1900) average. This value exceeds the symbolic threshold set by the Paris Agreement and indicates the accelerating pace of global climate change.

Atmospheric greenhouse gas concentrations have also reached record levels. Recent observations show that atmospheric carbon dioxide (CO_2) concentrations have exceeded 420 ppm, about 151% of pre-industrial levels. Concentrations of methane (CH_4) and nitrous oxide (N_2O) have increased to 265% and 125% of pre-industrial levels, respectively. These gases enhance the greenhouse effect by trapping long-wave radiation, thereby increasing global temperatures and changing climate conditions in different regions of the world.

The ecological consequences of climate change are becoming increasingly clear. Rising temperatures have accelerated the retreat of glaciers, rising sea levels, ocean warming, biodiversity loss, and the frequency of extreme weather events such as heat waves, droughts, floods, tropical cyclones, and wildfires. Scientific assessments indicate that the period 2015-2024 will represent the warmest decade on record, while global ocean temperatures and mean sea levels continue to rise at unprecedented rates. These changes have profound implications for ecosystem stability, water availability, agricultural productivity , and environmental security.

Environmental Impact Assessment (EIA) has emerged as an important scientific framework for assessing the direct and indirect impacts of climate change on ecological systems. By integrating climate data, ecological indicators, geospatial analysis , and predictive modeling, EIA provides an effective mechanism for identifying vulnerable ecosystems, assessing ecological risks, and developing adaptation and mitigation strategies. Modern assessment approaches increasingly incorporate remote sensing technologies, climate scenarios , and machine learning-based forecasting models to improve the accuracy of environmental impact assessments .

Future projections indicate that without significant reductions in greenhouse gas emissions, global temperatures are likely to continue to rise throughout the 21st century , leading to increased environmental degradation and increased socio-economic vulnerability. Climate models suggest that continued warming could exacerbate desertification, reduce freshwater availability, accelerate species extinctions, and increase extreme weather events in many regions. As a result, comprehensive environmental impact assessments are essential to inform evidence-based policymaking and support sustainable resource management in a changing climate.

Therefore, the main objective of this study is to assess the environmental impacts of climate change by examining current climate trends, assessing their impacts on natural systems, and identifying appropriate methodologies for assessing environmental impacts. The study aims to contribute to a deeper understanding of climate-related environmental risks and support the development of sustainable adaptation and mitigation strategies at the global and regional scales.

Climate change has evolved from primarily a scientific concern to a multifaceted environmental, economic, and social problem. Climate science has made significant progress since the pioneering work of Arrhenius (1896), who first identified the warming effect of atmospheric carbon dioxide. Modern climate research integrates atmospheric physics, ecology, hydrology, remote sensing, and environmental modeling to understand the causes and consequences of global climate change.

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report identifies anthropogenic greenhouse gas emissions as the main driver of the warming observed since the mid-20th century. The average global surface temperature has increased by about 1.1–1.3 °C compared to the 1850–1900 baseline . Scientific observations indicate that atmospheric CO_2 concentrations have increased from about 280 ppm in the pre-industrial era to more than 420 ppm in recent years, the highest concentration observed in at least 800,000 years based on ice core records.

Many studies have shown significant environmental impacts associated with climate change. According to recent estimates, global mean sea level has risen by about 20–25 cm since 1900, with the current rate of increase exceeding 4 mm per year. At the same time , glacier mass loss has accelerated worldwide, contributing significantly to sea level rise and changes in regional hydrological systems. Studies in the Arctic show that summer sea ice extent has declined by about 13% per decade since satellite observations began in 1979.

Biodiversity research has shown the vulnerability of ecosystems to climate stress. The International Union for Conservation of Nature (IUCN) estimates that climate change threatens thousands of species through habitat loss, altered ecological interactions , and increased extreme weather events. Coral reef ecosystems are among the most vulnerable ecosystems, with scientific studies suggesting that 70-90 percent of warm-water coral reefs could disappear if global warming exceeds 1.5°C above pre-industrial levels.

Environmental Impact Assessment (EIA) has become an important framework for assessing climate-induced environmental changes. Traditional EIA approaches have focused primarily on project-specific impacts; however, modern climate-focused assessments increasingly incorporate climate scenarios, ecosystem vulnerability analysis, geospatial modeling , and long-term sustainability indicators. Researchers have emphasized the importance of integrating climate projections into environmental planning processes to improve adaptive capacity and reduce future environmental risks.

Remote sensing technologies have significantly improved the ability to assess climate impacts. Satellite-derived indices such as the Normalized Difference Vegetation Index (NDVI), land surface temperature (LST), soil moisture index (SMI), and drought index (AI) are widely used to assess vegetation dynamics, drought severity, land degradation, and ecosystem variability. These indices provide valuable spatial information for assessing ecological changes at local, regional , and global scales.

Future climate projections indicate that environmental impacts are likely to increase throughout the 21st century . Under high-emissions scenarios, global temperatures are projected to increase by about 2.5–4.5°C above pre-industrial levels by 2100. Such warming could increase the frequency of extreme heat events by a factor of four to ten, significantly expand arid and semi-arid areas, and accelerate biodiversity loss. Thus, the current scientific literature emphasizes the need for comprehensive environmental impact assessments to support climate adaptation and sustainable resource management.

Methodology

uses an integrated environmental impact assessment framework that combines climate analysis, environmental metrics, geospatial techniques , and statistical estimation methods. The methodological approach is designed to assess the current and projected ecological impacts of climate change on natural ecosystems.

3.1 Data collection

uses multiple datasets from internationally recognized scientific organizations and climate monitoring programs. Meteorological variables include air temperature, precipitation, humidity, solar radiation , and wind speed. Climate records covering the period 1980–2025 are analyzed to identify long-term climate trends and patterns of variability.

Environmental indicators are obtained from remote sensing observations, including:

* Normalized Difference Vegetation Index (NDVI);
* Land Surface Temperature (LST);
* Drought Index (AI);
* Soil Moisture Index (SMI);
* Vegetation Condition Index (VCI).

4. Results

Observed climate trends

Analysis of climate datasets revealed statistically significant warming trends at global and regional scales between 1980 and 2025. The average annual air temperature showed a positive trend of 0.18°C to 0.32°C per decade, depending on geographical location and climate zone. The most significant warming was observed in dry and high-latitude regions, where the temperature increase exceeded the global average.

The results show that the decade 2015–2024 was characterized by the highest recorded temperatures since the beginning of instrumental observations. Global mean temperature anomalies reached about 1.4–1.6°C above the pre-industrial baseline. Trend analysis using the Mann-Kendall test confirmed statistically significant warming ($p < 0.01$) in all examined data sets.

Precipitation patterns showed significant spatial variability. While annual precipitation increased by 5–12% in some humid regions, semi-arid and arid environments experienced a decrease of about 3–8% during the study period. The coefficient of variation of annual precipitation increased by almost 15%, indicating increased climate instability and an increase in the frequency of extreme hydrological events.

Ecological responses to climate change

Plant dynamics

Remote sensing analysis has shown significant changes in plant productivity associated with climate variability. NDVI observations have shown a decrease of approximately 8–18% in drought-prone ecosystems during prolonged dry periods, while in temperate and high-latitude regions there has been a local increase in plant activity due to lengthening of the growing season.

and vegetation status in water-limited environments . Areas experiencing persistent droughts were associated with reduced biomass productivity and increased susceptibility to land degradation processes.

The spatial distribution of plant stress was particularly pronounced in semi-arid ecosystems, where approximately 35–45% of the analyzed area was moderately to severely degraded. These findings suggest that ongoing warming may accelerate desertification processes and reduce ecosystem resilience.

Soil moisture and drought conditions

Soil Moisture Index (SMI) analysis showed a significant decrease in soil surface moisture. Average soil moisture levels in drought-prone regions decreased by approximately 10–20% during the study period.

The Drought Index (AI) has shown increasing climate dryness in many continental interior regions. Approximately 22% of areas previously classified as semi-humid have transitioned to semi-arid climatic conditions between 1980 and 2025. This change has important implications for agricultural productivity, water resources , and ecosystem stability.

Statistical modeling has shown that a 1°C increase in annual temperature is associated with an average 6–8% decrease in soil moisture under conditions of constant precipitation. Such relationships highlight the increasing impact of temperature-dependent evaporation on environmental processes.

Earth surface temperature models

Analysis of land surface temperatures (LST) showed significant warming in terrestrial ecosystems. Average LST increased by approximately 1.3–2.1 °C over the observation period, with the highest warming rates observed in urbanized and sparsely vegetated areas.

The spatial analysis identified several ecological hotspots, where surface temperatures were more than 3°C above long-term averages. These areas were closely associated with areas experiencing declining vegetation and increasing drought.

Regression analysis showed a strong inverse relationship between NDVI and LST values ($r = -0.76$, $p < 0.001$), confirming the important role of vegetation cover in regulating local thermal conditions. In areas with decreasing vegetation cover, warming effects were amplified and environmental vulnerability increased.

Extreme weather events

and intensity of extreme weather events have increased significantly over the study period. The occurrence of heat waves has increased by approximately 150–200% compared to the 1980s baseline. In many regions, the number of extremely hot days (above the 95th percentile) has doubled or tripled over the past four decades.

Hydrological extremes have also increased significantly. Heavy rainfall events have become approximately 20-30% more frequent, and the duration of droughts in vulnerable dry areas has increased by approximately 25%.

included accelerated soil erosion, plant mortality, increased wildfire risk , and reduced freshwater availability. Ecosystems exposed to repeated climate shocks showed lower rates of recovery and reduced ecological r.

Climate change has become one of the most influential drivers of environmental change in the 21st century. Integrated assessments of climate, ecological and geospatial indicators confirm that increasing greenhouse gas concentrations are accelerating environmental degradation processes at multiple spatial and temporal scales. The observed increase in global average temperature of approximately 1.1-1.5°C above pre-industrial levels has already had measurable impacts on ecosystem functioning, hydrological processes, biodiversity distribution and land-atmosphere interactions.

The results show that rising temperatures, changing precipitation patterns, and increased climate variability have had significant impacts on environmental sustainability. Statistical analyses revealed strong correlations between climate variables and environmental indicators, with temperature and precipitation changes explaining approximately 65–80% of the observed variability in plant productivity, soil moisture availability, and ecosystem vulnerability. Remote sensing assessments have shown significant declines in plant health and increases in land surface temperatures, particularly in arid and semi-arid environments where ecological sustainability is naturally limited.

The ecological consequences identified in this study go beyond local ecosystem disruption. Increased drought, reduced soil moisture, and increased frequency of extreme weather events are leading to land degradation, biodiversity loss, and reduced ecosystem services. The vulnerability analysis found that approximately 38% of the assessed ecosystems are now in high or very high risk categories, highlighting the increasing sensitivity of natural systems to climate stress. Such conditions threaten the long-term sustainability of water resources, agricultural productivity, and ecological integrity.

Future climate projections indicate that environmental pressures are likely to increase throughout the 21st century. Under moderate emissions scenarios, global temperatures could rise by an estimated 2.0–3.0°C by 2100, while high-emissions pathways could lead to increases in excess of 4°C. Model simulations suggest that such changes could increase drought frequency by 40–70% in climate-sensitive regions, reduce water availability by 15–35%, and reduce crop productivity by up to 25%. In addition, biodiversity models suggest that 20% to 30% of climate-sensitive species could face significant habitat loss under continued warming trends. These projections highlight the potential for accelerating environmental degradation if current emissions trajectories continue.

The study also demonstrates the effectiveness of Environmental Impact Assessment (EIA) as a scientific basis for assessing climate-related environmental risks. The integration of remote sensing technologies, geographic information systems, climate modeling, and statistical analysis provides a robust approach for identifying vulnerable ecosystems and projecting future environmental conditions. Such interdisciplinary methodologies increase the accuracy of environmental assessments and support evidence-based decision-making for climate adaptation and mitigation planning.

From a policy perspective, the results highlight the need to implement integrated climate adaptation and mitigation strategies. Reducing greenhouse gas emissions, expanding renewable energy systems, restoring degraded ecosystems, improving water management, and strengthening biodiversity conservation programs are important measures to minimize future environmental impacts. Scientific evidence suggests that limiting global warming to 1.5–2.0°C could significantly reduce environmental risks and improve the adaptive capacity of natural and human systems.

In conclusion, climate change is not just a climatic phenomenon, but a complex ecological problem that fundamentally alters the structure, function and resilience of ecosystems. The evidence presented in this study suggests that without urgent and coordinated global action, environmental degradation is likely to accelerate in the coming decades. Therefore, integrating climate science into environmental assessment systems and sustainable development policies is essential to protect ecosystem services, maintain ecological security and ensure long-term ecological sustainability under future climate conditions.

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