

Emerging Environmental Challenges and Ecosystem Resilience in Jammu and Kashmir under Rapid Urbanization and Climate Change

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Abstract

Jammu and Kashmir represents one of the most environmentally diverse and ecologically sensitive regions of the western Himalaya, characterized by extensive forests, wetlands, rivers, lakes, alpine meadows, glaciers, agricultural landscapes, and mountainous ecosystems. These ecosystems provide essential services including water regulation, biodiversity conservation, climate regulation, soil protection, agricultural productivity, tourism, and livelihood support. However, rapid urbanization and accelerating climate variability are increasingly transforming the environmental and ecological characteristics of the region. Expansion of built-up areas, infrastructure development, population growth, land-use conversion, increasing vehicular pressure, solid-waste generation, wastewater discharge, and unplanned construction have placed considerable stress on natural ecosystems. Simultaneously, rising temperatures, changing precipitation patterns, declining snow cover, glacier retreat, extreme rainfall, floods, drought conditions, and changes in seasonal hydrology are creating additional pressures on ecological systems and human communities. The interaction between anthropogenic disturbances and climatic changes is particularly important because urban and degraded ecosystems often possess lower resilience to climate-related disturbances. This review examines the major emerging environmental challenges affecting Jammu and Kashmir under rapid urbanization and climate change and evaluates the capacity of regional ecosystems to absorb, adapt to, and recover from these pressures. Particular attention is given to urban expansion, forest degradation, water-resource stress, wetland deterioration, biodiversity loss, solid waste and wastewater pollution, land degradation, changing cryospheric conditions, and climate-induced hazards. The review further discusses ecosystem resilience, nature-based solutions, climate-resilient urban planning, watershed conservation, restoration of wetlands and forests, sustainable tourism, and community participation as potential pathways toward environmental sustainability.

Keywords: Jammu and Kashmir, climate change, urbanization, ecosystem resilience, environmental degradation, Himalayan ecosystems, sustainable development.

1. Introduction

Mountain ecosystems are among the most environmentally sensitive systems in the world because relatively small changes in temperature, precipitation, land use, or human pressure can produce significant ecological consequences. Jammu and Kashmir, situated within the western Himalayan region, contains a remarkable diversity of landscapes ranging from subtropical plains and agricultural areas to temperate forests, alpine meadows, high-altitude wetlands, glaciers, rivers, and lakes. These ecosystems support a wide range of ecological processes and provide essential resources and services to human populations. Water supply, agriculture, livestock, tourism, forest products, fisheries, hydropower, soil conservation, and biodiversity are closely connected with the health of these ecosystems [1].

In recent decades, however, Jammu and Kashmir has experienced substantial environmental transformation. Urban areas have expanded rapidly, particularly around major population centres, while roads, buildings, commercial establishments, tourism infrastructure, and other forms of development have increasingly occupied natural and agricultural landscapes. Urban expansion is accompanied by increasing generation of municipal solid waste, sewage, traffic emissions, construction debris, and other forms of environmental pressure.

When such development occurs without adequate spatial planning and environmental safeguards, natural drainage systems, wetlands, agricultural land, forests, and other ecological assets can become increasingly fragmented [2-3].

Climate change is adding another dimension to these pressures. Himalayan environments are particularly sensitive to changes in temperature and precipitation because snow, glaciers, soil moisture, vegetation,

and river flows are closely connected with climatic conditions. Changes in temperature can influence snow accumulation and melting, glacier mass balance, vegetation phenology, agricultural seasons, and water availability. Changes in precipitation can increase the likelihood of floods and landslides in some circumstances while contributing to drought and water stress in others.

The most important environmental challenge is therefore not urbanization or climate change considered independently. Rather, it is the interaction between rapid human-induced landscape transformation and changing climatic conditions. Urban expansion can reduce natural flood-storage areas and increase surface runoff, thereby amplifying the effects of intense rainfall. Deforestation and land degradation can increase erosion and landslide susceptibility. Wetland loss can reduce natural water-storage capacity. At the same time, climate change can place additional stress on ecosystems already weakened by pollution, fragmentation, and resource extraction [3-4]. The concept of ecosystem resilience provides a useful framework for understanding these interactions. Resilience refers broadly to the ability of an ecosystem or ecological-social system to absorb disturbances, maintain essential functions, adapt to changing conditions, and recover after disruption. Strengthening resilience in Jammu and Kashmir therefore requires not merely reducing individual pollutants but maintaining the ecological processes that enable forests, wetlands, rivers, agricultural landscapes, and urban ecosystems to function under changing environmental conditions.

2. Environmental and Ecological Setting of Jammu and Kashmir

The environmental diversity of Jammu and Kashmir results primarily from strong variations in altitude, topography, climate, geology, and hydrology. The region contains several distinct ecological zones, each with characteristic vegetation, soils, water resources, and human activities. The lower areas experience relatively warmer climatic conditions, while the Kashmir Valley and higher mountainous regions experience temperate to alpine conditions.

The Himalayan landscape is particularly important from a hydrological perspective. Snow and glacier systems contribute to river flows, while forests and wetlands regulate runoff and groundwater processes. Rivers, streams, springs, lakes, and wetlands provide water for agriculture, households, tourism, and ecosystems. Consequently, changes in land cover and climate can have consequences far beyond the immediate location where environmental disturbance occurs [5].

Forests are equally important. They provide habitat for wildlife, stabilize slopes, regulate water flows, reduce erosion, store carbon, and provide livelihood resources. Alpine meadows and high-altitude ecosystems support specialized plant and animal communities and contribute to pastoral livelihoods and tourism.

The environmental significance of these ecosystems makes Jammu and Kashmir highly dependent on ecological stability. At the same time, increasing urbanization and economic development are creating growing demand for land, water, infrastructure, energy, and natural resources.

3. Rapid Urbanization and Land-Use Transformation

Urbanization is one of the most visible forms of environmental transformation in Jammu and Kashmir. Srinagar and other growing urban centres have expanded beyond their traditional boundaries into surrounding agricultural, wetland, forest, and rural landscapes. Expansion of residential colonies, roads, commercial areas, institutions, tourism infrastructure, and other built-up structures has progressively altered land-use patterns. The conversion of natural and agricultural land into built-up surfaces changes the functioning of landscapes. Concrete and asphalt reduce soil infiltration and increase surface runoff. Natural drainage channels can become obstructed or modified, increasing the risk of localized flooding during intense rainfall. The loss of vegetation reduces evapotranspiration and can increase local heat accumulation [6]. Urban expansion can also fragment habitats. Even where large areas of natural vegetation remain, roads and settlements can divide ecosystems into smaller patches. Habitat fragmentation can restrict movement of wildlife, reduce genetic connectivity, and increase exposure to human disturbance. Land-use change therefore represents more than a change in the visual landscape. It modifies hydrological processes, ecological connectivity, soil functions, biodiversity, and local climatic conditions.

4. Climate Change and Changing Environmental Conditions

Climate change is increasingly recognized as a major driver of environmental transformation in the Himalayan region. Jammu and Kashmir is particularly sensitive because many ecological and socioeconomic systems depend on temperature-sensitive snow and water processes.

Increasing temperatures can affect the timing and intensity of snowmelt, influence glacier mass balance, alter plant growth cycles, and increase evaporation. These processes can affect water availability for agriculture, domestic use, hydropower, and ecosystems [7]. Precipitation changes can be equally important. A shift from snowfall toward rainfall at certain elevations can modify seasonal water storage. Intense rainfall events can generate flash floods, soil erosion, landslides, and sediment transport. Conversely, prolonged dry periods can reduce water availability and increase agricultural stress. The consequences of climate change are therefore not uniform.

Some communities and ecosystems may experience increasing flood risk, while others may face water shortages. This spatial and seasonal variability makes climate adaptation particularly challenging.

5. Forest Ecosystems and Environmental Degradation

Forests are central to ecosystem resilience in Jammu and Kashmir. They stabilize mountain slopes, regulate water flows, store carbon, support biodiversity, and provide a wide range of ecosystem services. However, forest ecosystems are exposed to multiple pressures including infrastructure development, illegal extraction, forest fires, grazing pressure, land-use change, pests, and climatic stress [8]. Climate change can increase forest vulnerability by modifying temperature and moisture regimes. Warmer conditions can affect species composition and regeneration patterns, while changing precipitation can increase water stress in certain forest types. Forest degradation can create a feedback mechanism. Loss of vegetation increases soil erosion and runoff, which can contribute to sedimentation of rivers and lakes. Reduced vegetation cover also decreases carbon storage and habitat quality. Forest conservation should therefore be considered an essential component of climate adaptation rather than simply a biodiversity objective.

6. Wetlands and Lake Ecosystems under Pressure

Wetlands and lakes represent some of the most vulnerable ecosystems in the region. Dal Lake, Wular Lake, Hokersar, and other wetland systems provide habitat for aquatic organisms and migratory birds while performing important water-storage and nutrient-cycling functions.

Urbanization, encroachment, agricultural runoff, wastewater discharge, solid waste, sedimentation, invasive species, and hydrological modification have affected several wetland ecosystems. The deterioration of Dal Lake provides an important example of how long-term human pressure can alter an urban wetland ecosystem [9]. Climate change may intensify these pressures by altering water levels, evaporation rates, temperature regimes, and seasonal hydrology. Wetlands that are already degraded may have less capacity to absorb additional disturbances [10]. Conservation of wetlands should therefore involve protection from encroachment, restoration of natural hydrological connections, reduction of nutrient and pollutant inputs, control of invasive species, and regular ecological monitoring.

7. Water Resources and Emerging Water Stress

Water resources are fundamental to both ecological and socioeconomic systems in Jammu and Kashmir. The region's rivers, lakes, springs, glaciers, snowfields, and groundwater systems form an interconnected hydrological network [11]. Climate change may alter this network through changes in snow accumulation, glacier melt, rainfall patterns, and evaporation. At the same time, population growth and urbanization increase water demand. Urban water demand is increasing as settlements expand, while pollution can reduce the amount of water that is suitable for human or ecological use.

Contamination of rivers and lakes by untreated wastewater, solid waste, agricultural runoff, and other pollutants can therefore create water scarcity even when total water availability remains significant [12]. This distinction between physical water availability and usable water availability is important for environmental planning.

8. Solid Waste and Wastewater Pollution

Rapid urbanization inevitably increases waste generation. Municipal solid waste, plastic waste, construction debris, sewage, and wastewater can place considerable pressure on urban and aquatic ecosystems when collection and treatment systems fail to keep pace with population growth [13]. Plastic pollution is an emerging concern because plastics can persist for long periods and fragment into microplastics. These particles may enter rivers, lakes, soils, and biological systems. Wastewater presents another major challenge. Untreated or inadequately treated sewage introduces organic matter, nutrients, pathogens, and other contaminants into receiving waters. Nutrient enrichment can accelerate eutrophication in lakes and wetlands. The solution requires an integrated waste-management system emphasizing waste reduction, segregation, recycling, wastewater treatment, safe disposal, and enforcement of environmental standards.

9. Biodiversity Loss and Habitat Fragmentation

Jammu and Kashmir supports diverse plant and animal communities because of its wide range of habitats. However, biodiversity is increasingly threatened by habitat fragmentation, land-use change, pollution, climate change, invasive species, and human disturbance [14]. Urban expansion can fragment wildlife habitats, while infrastructure development can create barriers to movement. Changes in temperature and precipitation may force species to shift their geographical ranges. Species that are unable to migrate or adapt rapidly may become increasingly vulnerable. High-altitude species may face particular challenges because suitable climatic zones can become increasingly restricted. Changes in alpine vegetation can also affect grazing systems and other ecosystem services. Maintaining ecological corridors and protecting habitat connectivity are therefore important elements of biodiversity conservation.

10. Glacier and Snow-System Changes

The cryosphere is a particularly important component of the Himalayan environment. Snow and glaciers function as natural water-storage systems and contribute to streamflow and river discharge [15]. Changes in glacier mass and snow cover can modify the timing and availability of water. In the short term, accelerated melting may increase water availability in some periods, while long-term loss of ice reserves may reduce dry-season contributions. Changes in snow cover also influence soil moisture, vegetation, agriculture, and ecosystem processes. The implications extend to hydropower, tourism, pastoralism, and downstream communities.

Monitoring glacier mass balance, snow cover, streamflow, and temperature is therefore essential for developing long-term climate adaptation strategies.

11. Natural Hazards and Increasing Vulnerability

Jammu and Kashmir is naturally exposed to floods, landslides, avalanches, earthquakes, cloudburst-related events, and other hazards. Environmental degradation and urban expansion can increase vulnerability to these hazards [16]. Construction on floodplains and natural drainage areas can reduce the capacity of landscapes to absorb intense rainfall. Removal of vegetation can increase slope instability and erosion. Road construction in mountainous terrain can disturb slopes and alter drainage. Climate change can further modify hazard patterns by influencing precipitation intensity, snow conditions, and temperature. Disaster-risk reduction must therefore be integrated with land-use planning and ecosystem conservation.

12. Agricultural Ecosystems and Climate Vulnerability

Agriculture is closely connected with environmental conditions and is therefore particularly sensitive to climate change and resource degradation. Changes in rainfall, temperature, snowfall, water availability, and extreme weather can affect crop productivity and agricultural calendars [17]. Agricultural expansion and intensification can also affect ecosystems through fertilizer runoff, pesticide use, soil erosion, and water extraction. Sustainable agriculture can help address these pressures through crop diversification, integrated nutrient management, conservation agriculture, efficient irrigation, agroforestry, organic-matter management, and climate-resilient varieties. Agricultural landscapes should increasingly be viewed as part of the broader ecological system rather than isolated production areas.

13. Tourism and Environmental Pressure

Tourism is an important component of Jammu and Kashmir's economy and provides substantial employment and income. However, rapid tourism growth can place pressure on water resources, waste-management systems, transport infrastructure, forests, wetlands, and landscapes. Popular destinations can experience seasonal concentrations of visitors that exceed local infrastructure capacity. Increased traffic contributes to air pollution and congestion, while poorly managed solid waste can degrade natural environments [12]. Sustainable tourism should therefore emphasize carrying capacity, waste management, public transportation, energy efficiency, responsible construction, and conservation of ecologically sensitive areas.

Tourism can ultimately contribute to conservation if local communities receive economic benefits from maintaining environmental quality.

14. Ecosystem Resilience in Jammu and Kashmir

Ecosystem resilience depends on ecological diversity, connectivity, functional redundancy, resource availability, and the ability of ecosystems to recover after disturbance. Healthy ecosystems generally possess greater capacity to absorb environmental shocks than fragmented or highly degraded ecosystems.

In Jammu and Kashmir, resilience is increasingly being affected by multiple simultaneous pressures. A wetland affected by sewage and encroachment may have less capacity to respond to extreme rainfall. A degraded forest may be more vulnerable to landslides and drought. An urban area lacking natural drainage systems may be more exposed to flooding [9]. Resilience therefore requires addressing underlying environmental degradation rather than focusing exclusively on disaster response.

15. Nature-Based Solutions for Environmental Resilience

Nature-based solutions provide an important pathway for strengthening environmental resilience. Wetland restoration can increase flood-storage capacity, while urban green spaces can reduce heat and improve stormwater infiltration [5]. Forest restoration can reduce erosion and strengthen slope stability. Riparian vegetation can improve water quality and reduce sediment transport. Urban tree planting can provide shade, reduce heat exposure, and improve air quality [7]. Such approaches are particularly valuable because they can provide multiple benefits simultaneously. A restored wetland, for example, can provide biodiversity habitat, flood regulation, water purification, recreation, and carbon storage.

16. Urban Planning and Climate-Resilient Development

Future urban development in Jammu and Kashmir needs to incorporate environmental considerations from the earliest stages of planning. Urban growth should be guided by scientifically prepared land-use plans that identify wetlands, flood-prone areas, drainage channels, forests, agricultural land, and other ecologically important areas [13]. Development should be concentrated in areas with suitable infrastructure while environmentally sensitive areas should receive stronger protection. Urban drainage systems should incorporate natural water-retention features, permeable surfaces, rainwater harvesting, and restored drainage corridors [15]. Climate-resilient urban planning should also consider heat stress, water availability, waste management, air pollution, and disaster risk.

Table 1: Major environmental challenges and potential pathways for strengthening ecosystem resilience in Jammu and Kashmir

Environmental challenge	Major drivers	Key ecological consequences	Implications for ecosystem resilience	Potential management response
Rapid urbanization	Population growth, infrastructure expansion and unplanned construction	Habitat fragmentation, loss of agricultural and wetland areas, increased runoff	Reduced ecological connectivity and greater flood vulnerability	Climate-sensitive land-use planning and compact urban development
Climate change	Rising temperature, changing precipitation and extreme events	Altered hydrology, vegetation changes and increased hazard exposure	Reduced capacity of ecosystems to absorb climatic shocks	Climate adaptation and ecosystem-based management
Wetland degradation	Encroachment, sewage, sedimentation and land-use change	Habitat loss, eutrophication and reduced water-storage capacity	Lower flood regulation and biodiversity-supporting capacity	Wetland protection, restoration and pollution control
Forest degradation	Land conversion, infrastructure, fires and resource extraction	Biodiversity loss, erosion and reduced carbon storage	Greater vulnerability to drought, landslides and climate stress	Forest restoration and habitat connectivity
Water pollution	Sewage, agricultural runoff and solid waste	Nutrient enrichment, contamination and aquatic ecosystem degradation	Reduced capacity of aquatic systems to recover from disturbance	Wastewater treatment and catchment-based pollution control
Water-resource stress	Climate variability, urban demand and changing snow and glacier conditions	Seasonal water shortages and altered river flows	Increased vulnerability of communities and ecosystems	Water conservation, rainwater harvesting and efficient irrigation
Solid-waste accumulation	Urban growth, tourism and inadequate waste infrastructure	Soil, water and landscape pollution	Reduced environmental quality and ecological functioning	Source segregation, recycling and scientific waste management
Biodiversity loss	Habitat fragmentation, pollution and climate change	Decline and displacement of species	Reduced ecological stability and functional diversity	Protected areas, ecological corridors and habitat restoration
Soil degradation	Erosion, construction, intensive agriculture and vegetation loss	Loss of soil fertility and increased sedimentation	Reduced land productivity and watershed resilience	Soil conservation, agroforestry and sustainable farming
Tourism pressure	High visitor concentrations, infrastructure and waste generation	Resource consumption, pollution and habitat disturbance	Reduced carrying capacity of sensitive ecosystems	Sustainable tourism and ecological carrying-capacity assessment
Natural hazards	Floods, landslides, avalanches and extreme rainfall	Infrastructure damage, soil loss and habitat disturbance	Increased social and ecological vulnerability	Ecosystem-based disaster-risk reduction and hazard-sensitive planning

20. Conclusion

Jammu and Kashmir is experiencing a period of profound environmental transformation in which rapid urbanization and climate change are interacting with existing ecological pressures. Expansion of settlements and infrastructure, land-use conversion, wastewater discharge, solid-waste generation, habitat fragmentation, forest degradation, wetland loss, and increasing resource demand are weakening ecological systems. At the same time, climatic changes involving temperature, precipitation, snow, glacier conditions, and extreme weather are creating additional stresses. The central concern is the cumulative nature of these pressures. Ecosystems that have already been degraded by human activities may have reduced capacity to absorb climatic disturbances. Consequently, environmental management must move beyond isolated interventions and adopt a resilience-based approach. Strengthening ecosystem resilience in Jammu and Kashmir requires the protection and restoration of forests, wetlands, rivers, lakes, agricultural landscapes, and other ecological assets. Urban planning should incorporate environmental carrying capacity and climate-risk considerations, while wastewater and solid-waste systems need to expand alongside urban growth. Sustainable agriculture can reduce pressure on soil and water resources, while sustainable tourism can align economic development with ecosystem conservation. Nature-based solutions provide particularly promising opportunities because they can simultaneously address climate adaptation, biodiversity conservation, disaster-risk reduction, and human wellbeing. Restoration of wetlands, protection of riparian zones, forest regeneration, urban green infrastructure, watershed conservation, and ecological corridors should therefore become integral components of regional development planning.

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