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UNDERSTANDING MIGRATION PATTERNS OF ANIMALS AND SOCIO-ECOLOGICAL TRANSITIONS IN GARHWAL REGION (UTTARAKHAND) DUE TO CLIMATE CHANGE

Dr. Sandeep Kumar [1]

[1] Assistant Professor, Department of Zoology Government Degree College, Satpuli, Khairasain, Pauri Garhwal, Uttarakhand, India

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ABSTRACT

The Garhwal region of Uttarakhand, situated in the central Himalayas, stands as one of India's most ecologically diverse and environmentally sensitive zones. Encompassing a vast altitudinal range, from subtropical valleys to alpine meadows and glaciated peaks, it harbors a unique assemblage of flora and fauna that have evolved intricate adaptations to the region's climatic variability. The lives of both wild and domesticated animals in this mountainous landscape are deeply intertwined with seasonal rhythms, resource availability, and altitudinal migration patterns that have persisted for centuries. These migratory cycles, whether of pastoral herds moving to the "bugyals" or of wildlife following the gradient of vegetation and temperature, constitute the ecological backbone of Garhwal's mountain systems. Here, we shall delve into the intricacies and understandings of changing/transitioning migratory patterns of animals in the concerned region, driven mainly by climate change. We shall also (briefly) allude towards the impacts laid upon socio-economic and cultural variables, in an effort to understand the parallel connections between climate change, anthropocentric dynamics and animal/livestock patterns.

Keywords: Climate Change, Animal Migration, Livestock, Anthropocentric Development, Himalayas

1. INTRODUCTION

In recent decades, the accelerating pace of climate change has begun to disrupt this delicate equilibrium. Rising temperatures, erratic precipitation, reduced snowfall, and the retreat of glaciers are profoundly altering the phenology and spatial dynamics of ecosystems across the region. These climatic perturbations have cascading effects on the migration of both wild and domesticated species, reshaping patterns that were once dictated by predictable seasonal cues. The consequences extend beyond ecology, influencing local livelihoods, traditional knowledge systems, and the cultural fabric of Himalayan communities that have long depended on the cyclical movement of animals for sustenance and identity. This paper examines the multifaceted impacts of climate change on animal migration in the Garhwal Himalaya, with particular emphasis on the ecological, physiological, and

socio-economic dimensions of this transformation. By integrating insights from environmental science, ethno-ecology, and climate studies, the discussion seeks to elucidate how global climatic forces manifest in localized ecological disruptions, threatening not only biodiversity but also the enduring human–environment relationships that define the Himalayan world.

2. TRANSITION IN MIGRATION PATTERNS

The Garhwal region of Uttarakhand, nestled within the central Himalayas, represents one of the most ecologically intricate and culturally significant landscapes in India. Characterized by dramatic altitudinal gradients, ranging from subtropical foothills to the snow-clad summits of peaks such as Nanda Devi, Trisul, and Kedarnath, Garhwal forms a vital ecological corridor for a wide range of migratory species, both wild and domesticated. For centuries, these mountains have served as seasonal homes for a mosaic of animal populations, including ungulates, birds, and pastoral livestock, whose migration rhythms are intimately synchronized with the seasonal cycles of temperature, precipitation, and vegetation. Yet, as the climate of the Himalayas undergoes rapid transformation, these ancient migratory systems are being disrupted in profound and often irreversible ways. Migration in the Garhwal Himalaya has long been governed by the predictable seasonality that defines high mountain ecologies. The steep environmental gradients, from the lush valleys of the Bhagirathi and Alaknanda rivers to the alpine meadows (bugyals) above 3,000 meters, create a spatially dynamic but temporally stable system where animals move to optimize access to food, water, and favorable microclimates. For domestic herds maintained by pastoral communities such as the Bhotiya and Van Gujjar tribes, transhumance, the seasonal migration between low-altitude winter pastures and high-altitude summer meadows, has historically ensured the sustainability of both herds and grasslands. Similarly, wild species such as the Himalayan tahr (Hemitragus jemlahicus), the musk deer (Moschus chrysogaster), and the snow leopard (Panthera uncia) exhibit altitudinal migrations in response to snow cover, prey distribution, and thermal comfort zones. Migratory birds, including the Himalayan monal (Lophophorus impejanus) and several species of thrushes and warblers, also track seasonal resource availability along these altitudinal gradients. However, climate change has begun to destabilize these finely tuned migratory rhythms. Rising temperatures, irregular precipitation, and shifting snowlines are altering the ecological cues that historically triggered seasonal movements.

The Himalayas are warming at nearly twice the global average rate, a phenomenon often described as “elevation-dependent warming” (Xu et al., 2009), which has already resulted in the upward migration of vegetation zones by 200–400 meters in some parts of Uttarakhand. This “vertical shifting” of ecological niches has cascading effects on animal migrations. Herbivores that once moved upward in summer to graze on alpine meadows now find these pastures desiccated earlier due to premature snowmelt and reduced soil moisture. Consequently, their migration windows are shortening, and their foraging ranges are contracting. For pastoral livestock, this change manifests in delayed or truncated transhumance cycles. The traditional movement of sheep, goats, and yaks to the alpine “bugyals”, such as Bedni, Dayara, and Panwali, used to follow a well-established seasonal rhythm: ascending in late May as snow receded, and returning to lower valleys by late September. Today, early snowmelt and late monsoons have blurred these boundaries. Pastures may dry up before the herds arrive, or become waterlogged from unseasonal rainfall, increasing the risk of fodder scarcity and disease

outbreaks. These disruptions not only threaten the economic stability of pastoralists but also lead to overgrazing in limited zones, accelerating soil erosion and the loss of native alpine flora. Wildlife species, too, are displaying altered migration patterns that reveal the ecological consequences of climate variability. The Himalayan tahr, which traditionally descended to forested slopes during harsh winters, is now observed remaining at higher altitudes for longer periods due to milder winters. Conversely, species such as the musk deer and serow (Capricornis thar) are being pushed to even higher elevations in search of cooler habitats, thereby compressing their ecological niches and increasing interspecies competition. This upward displacement intensifies the risk of habitat fragmentation, particularly as vegetation belts shift unevenly, creating discontinuities between food sources and shelter zones. Climate-induced changes in migration are also reshaping predator-prey dynamics. The snow leopard, a flagship species of the Garhwal Himalaya, depends on the predictable movement of prey species like bharal (Pseudois nayaur) and Himalayan tahr.

As prey distributions shift unpredictably due to temperature anomalies and vegetation changes, snow leopards are forced to expand their range or descend into human-dominated areas, increasing the frequency of livestock predation and human-wildlife conflict. Similarly, black bears (Ursus thibetanus) and leopards (Panthera pardus) are increasingly sighted in mid-altitude villages, suggesting an ecological displacement driven by climate as well as habitat fragmentation. Among avian species, the effects are equally conspicuous. Migratory birds that once used Garhwal's temperate forests and alpine wetlands as stopover sites during their seasonal journeys are arriving earlier or later than historical averages. Phenological studies have shown that rising spring temperatures in the Himalayas advance flowering and insect emergence, desynchronizing the timing of food availability for arriving birds Saino et al. (2024). Consequently, species such as the verditer flycatcher (Eumyias thalassinus) and the blue-capped rock thrush (Monticola cinclorhyncha) face mismatches between migration timing and resource abundance, potentially reducing breeding success. Some long-distance migratory birds, unable to adapt to altered seasonal cues, may even bypass traditional stopover zones in Garhwal altogether, threatening the region's role as a crucial node in the Central Asian flyway. Beyond biological responses, anthropogenic pressures amplify the climatic impacts on migration. Deforestation, road construction, hydropower projects, and unregulated tourism are fragmenting habitat corridors essential for animal movement. The corridors linking the Kedarnath Wildlife Sanctuary, Nanda Devi Biosphere Reserve, and Rajaji National Park, once continuous migration pathways for elephants, ungulates and carnivores, are increasingly obstructed by human settlements and infrastructure. As climate change forces species to shift ranges, the loss of such connectivity magnifies vulnerability, trapping animals in shrinking habitat patches with declining resource availability. These migratory disruptions have broader ecological implications. Migration serves vital ecosystem functions, regulating nutrient flows, maintaining genetic exchange and supporting trophic balance. When migration patterns collapse or shift, it destabilizes the ecological equilibrium of entire landscapes. Reduced herbivore movement can alter vegetation dynamics, while shifts in predator ranges can influence prey populations and even affect agricultural pest cycles. Thus, the alteration of migration patterns in Garhwal is not merely a zoological concern but a systemic transformation of mountain ecology. The socio-cultural dimensions of these changes are equally profound. In Garhwal, animal migrations (whether of wild species or pastoral herds) are woven into local traditions, folklore, and livelihood practices. The timing of livestock transhumance, bird arrivals, and wildlife sightings

often inform local calendars and rituals. Climate-induced disruptions, therefore, signify not only ecological imbalance but also a cultural disorientation, a loss of temporal rhythm that once synchronized human life with the pulse of the mountains. In addressing these challenges, the integration of ecological monitoring, local knowledge, and adaptive management is imperative. Establishing climate-resilient migration corridors, conserving altitudinal gradients of habitat, and restoring degraded alpine meadows are essential for maintaining the integrity of migratory systems. Community-based conservation programs that engage pastoralists, forest dwellers, and local youth in participatory monitoring can bridge scientific and traditional perspectives. Furthermore, incorporating phenological data and climate projections into wildlife and livestock management plans can help anticipate and mitigate migration mismatches. Ultimately, the transformation of animal migration in the Garhwal region encapsulates the broader narrative of Himalayan climate change, where the warming of the mountains translates into a reorganization of life itself. The movement of animals through these landscapes has long been a symbol of ecological resilience and adaptability. Yet today, as the mountains warm and the seasons blur, migration increasingly reflects displacement rather than renewal. Safeguarding the migratory patterns of Garhwal's fauna thus demands more than conservation; it requires reimagining coexistence between climate, culture, and the living systems that bind them.

3. TRANSITIONS IN LIVESTOCK PATTERNS

The Uttarakhand Himalaya, a region celebrated for its ethereal landscapes, cultural sanctity, and rich biodiversity, epitomizes the ecological complexity and fragility of the greater Himalayan system. Often referred to as *Devbhoomi*, or "the land of the gods," it encompasses sacred shrines and meditative spaces interwoven within mountain ecosystems that sustain both natural and human life. Beyond its spiritual and scenic grandeur, the region's economy and culture are deeply rooted in agriculture and animal husbandry. Livestock rearing has traditionally formed the backbone of rural livelihoods, particularly among pastoral and tribal communities such as the Gujjars and the Bhotiya tribes, who inhabit the high-altitude valleys of Johar, Byans, Niti, and Bhagirathi. These groups have historically maintained a symbiotic relationship with their environment, relying on transhumance, forest grazing, and intricate ecological knowledge systems to sustain both their herds and their way of life. Uttarakhand's livestock economy encompasses a wide range of species (cattle, buffalo, sheep, goats, pigs, ponies and poultry) each adapted to specific altitudinal and climatic niches. Livestock holdings are typically small and mixed, reflecting both the ecological diversity of the region and the subsistence-oriented nature of its agrarian economy. However, despite the richness of species diversity, productivity levels remain modest due to limited fodder resources, disease pressures, and the challenging topography that constrains large-scale mechanization or intensive rearing practices. Animal husbandry in the region thus operates at the intersection of ecology, economy, and tradition, maintaining resilience through diversity rather than through scale. In recent decades, however, the intricate equilibrium that underpins these livestock systems has been profoundly disrupted by climate change. The observable shifts (rising temperatures, erratic precipitation, shortened winters and diminished snowfall) have begun to alter the ecological rhythms upon which traditional pastoral practices depend. Seasonal migration patterns that once synchronized with the availability of alpine pastures (bugyals) are increasingly mismatched. Early snowmelt and irregular rainfall reduce the period of pasture regeneration, creating fodder shortages during

critical summer months. This ecological mismatch results in overgrazing of lower-altitude grasslands and degradation of high-altitude meadows, triggering cascading effects on soil quality, water retention, and vegetation diversity.

Temperature rise has emerged as one of the most pervasive threats to livestock health and productivity. Animals that evolved in the cool Himalayan climate, such as the Garhwali goat and native hill cattle, are now increasingly exposed to heat stress, which diminishes milk yield, slows growth, and weakens immune resilience. Prolonged exposure to elevated temperatures and humidity creates physiological strain, leading to dehydration and increased susceptibility to parasites and vector-borne diseases. These factors not only undermine the health of animals but also destabilize household economies, as livestock serve as both productive assets and financial security in rural Uttarakhand. In many cases, the death or illness of livestock translates directly into a loss of food, income, and cultural continuity. The issue of water scarcity compounds these challenges. Traditionally, the Himalayan slopes have been nourished by a network of springs, streams, and rivers fed by glacial and snowmelt systems. Yet these sources are increasingly unreliable due to altered precipitation regimes and shrinking snow reserves. The seasonal desiccation of streams, once perennial, has forced households to walk greater distances for water, while also constraining irrigation and fodder cultivation. Reduced availability of green fodder has heightened the dependence on purchased feed, intensifying the economic burden on smallholders. Water stress, thus, functions as a multiplier of vulnerability, affecting not only livestock directly but also the ecological and social systems that support them. Another insidious impact of climate change in the region lies in the epidemiological transition among animal populations. Warmer temperatures and shifting humidity patterns have expanded the geographical range and duration of disease vectors, increasing the prevalence of ailments such as foot-and-mouth disease, tick infestations, and parasitic infections. Simultaneously, heat-induced physiological stress suppresses immune function, making livestock more susceptible to opportunistic infections. In ecosystems already struggling with fodder scarcity and water constraints, these health burdens further diminish productivity and erode the economic viability of pastoralism. The rising veterinary costs and loss of valuable animals can devastate household's dependent on livestock for subsistence and cultural identity. Equally concerning is the threat to indigenous livestock breeds that have co-evolved with the region's rugged terrain and climatic variability.

Breeds such as the Garhwali goat and local hill cattle are invaluable genetic resources, uniquely adapted to cold tolerance, low-nutrient forage, and high mobility. However, their adaptive capacity is now being outpaced by the rate of environmental change. Warmer temperatures and disease pressures are reducing their reproductive success and survivability, while the shrinking of traditional grazing lands and decline in transhumant herding practices are eroding the cultural knowledge embedded in their management. In response, some farmers have begun crossbreeding local varieties with high-yield commercial breeds to maintain productivity, a short-term adaptation that risks the long-term loss of genetic diversity and the erosion of the socio-ecological wisdom accumulated over centuries. The cumulative effects of these transformations highlight a deeper structural challenge: the erosion of climate resilience in traditional mountain livelihoods. What was once a finely balanced system of rotational grazing, mixed herding, and seasonal migration is now under strain from both environmental unpredictability and socio-economic change. As younger generations seek alternative livelihoods in urban areas, the intergenerational transfer of pastoral knowledge declines, further weakening adaptive capacity. Meanwhile, policy

interventions remain limited in scope, often emphasizing short-term productivity over the conservation of local breeds, water systems, and grazing commons. In essence, the livestock systems of Uttarakhand exemplify the vulnerability of high-altitude agro-ecological zones to climate variability. They also reveal the interdependence between ecological processes and social resilience. The transformation underway is not merely an environmental phenomenon, it represents a reconfiguration of human-environment relations, where centuries-old pastoral practices confront the pressures of a warming world. The path forward must therefore integrate scientific innovation with traditional knowledge, promoting sustainable pasture management, water conservation, and breed preservation. Only through such integrative and adaptive frameworks can the livestock-based livelihoods of the Uttarakhand Himalaya endure in the face of an increasingly uncertain climatic future.

4. SOCIO-ECOLOGICAL TRANSFORMATIONS

Climate change represents a pervasive global phenomenon exerting profound and multifaceted impacts on both social and ecological systems. It has evolved into one of the most pressing environmental and socio-economic challenges of the contemporary world, characterized by its accelerating pace and far-reaching implications. Although its manifestations are global, developing nations bear the heaviest burden due to their limited adaptive capacities, infrastructural constraints, and dependence on climate-sensitive sectors such as agriculture and water resources. In these regions, particularly across Africa and Asia, climate change manifests in intensified and more frequent extreme weather events, irregular precipitation patterns, and rising average temperatures. These changes amplify vulnerabilities by disrupting the delicate balance between human livelihoods and ecological stability. The agricultural, hydrological, and ecological systems that underpin food security and human survival have been especially susceptible to climate variability. Shifts in precipitation and temperature regimes have significantly influenced crop productivity and the sustainability of agricultural systems. Reduced water availability and unpredictable monsoon behavior have further complicated irrigation practices and soil moisture retention, undermining traditional cropping patterns. The interlinkages between climate, crop performance, and food security illustrate the systemic nature of these transformations, as rural communities dependent on rain-fed agriculture increasingly face food scarcity and economic instability. The resulting strain often triggers rural-urban migration, as seen in many Himalayan regions, where land abandonment has become a growing concern.

Mountain ecosystems, covering nearly a quarter of the Earth's surface, constitute vital ecological zones that sustain biodiversity, regulate hydrological cycles, and support approximately one-tenth of the world's population. These regions are critical repositories of biological, cultural, and agro-diversity, harboring unique species and traditional farming systems that have co-evolved with their environments over centuries. However, their ecological fragility renders them exceptionally vulnerable to climatic disruptions. Rising temperatures, erratic precipitation, and the increased occurrence of natural hazards such as landslides, glacial lake outbursts, and floods threaten both ecological integrity and human livelihoods. Furthermore, the socio-economic marginalization of mountain communities, exacerbated by geographic isolation and limited infrastructure, intensifies their exposure to the adverse impacts of environmental change. In mountain societies, climate change has driven marked social transformations

alongside ecological shifts. Social change in this context encompasses demographic transitions, occupational diversification, and alterations in livelihood strategies, while ecological change refers to evolving land use patterns, degradation of natural resources, and modification of cropping systems. The Himalayan region, for instance, has witnessed warmer winters, increasing aridity, and shifts in the agricultural calendar. These conditions have encouraged the introduction of non-traditional crops such as tomatoes and other vegetables, offering new sources of income to mountain farmers. Conversely, traditional crops such as apples have declined in productivity and economic relevance due to the loss of optimal climatic conditions. Such transitions reveal the intricate coupling between climate dynamics and socio-economic adaptation. Similar processes are observable in other mountain systems such as the Andes, where climatic fluctuations have altered hydrological regimes, reduced glacier volumes, and disrupted local economies. The retreat of Andean glaciers, visible evidence of global warming, has affected tourism, agriculture, and access to freshwater resources, compelling local populations to modify agricultural practices and diversify income sources. The loss of perennial ice and changing rainfall patterns not only reshape ecosystems but also reconfigure cultural and social relations tied to the natural landscape. Within the Himalayan context, the Garhwal region stands as a critical case study of socio-ecological transformation. As part of the larger Himalayan mountain system, Garhwal exhibits pronounced sensitivity to environmental change due to its complex physiography, steep gradients, and dependency on natural resources.

The region's agricultural base, largely composed of subsistence farming systems, has experienced declining productivity as a consequence of changing temperature regimes and erratic rainfall. The resulting food insecurity has compelled migration from high-altitude villages toward more fertile plains and urban centers, particularly the Tarai and Doon valleys. These demographic shifts are reshaping social structures, altering traditional livelihoods, and redefining the relationship between humans and their environment. At the same time, Garhwal's landscape has undergone considerable transformation in land use and cropping patterns. Cash crops have increasingly replaced traditional cereals, reflecting both economic aspirations and adaptive responses to climatic uncertainty. Forest cover remains extensive, yet ecological pressures from deforestation, overgrazing, and human settlement have begun to erode the region's environmental resilience. The interplay between climatic and social factors, like temperature rise, rainfall variability, education-driven migration, modernization and changing food habits, has produced a dynamic mosaic of socio-ecological change. These processes collectively signify a broader reorganization of mountain life under climate stress, where adaptation is both a necessity and a negotiation between tradition and modernity. In conclusion, climate change in mountain ecosystems exemplifies a complex entanglement of environmental processes and human agency. The transformations occurring in regions like the Garhwal Himalaya underscore that climate change is not merely an ecological phenomenon but a socio-ecological restructuring of entire ways of life. As traditional agricultural systems, cultural practices, and ecological balances are disrupted, communities must navigate the dual challenge of preserving their natural heritage while innovating sustainable adaptive strategies. The future of mountain societies, therefore, lies in integrating scientific understanding, local knowledge, and policy interventions to create resilient socio-ecological systems capable of enduring the uncertainties of a changing climate.

5. MORE INTO CLIMATE INDUCED TRANSITIONS

The Garhwal Himalaya, extending across a vast and diverse topographical range between approximately 29°31'9" N to 31°26'5" N and 77°33'5" E to 80°6'0" E, occupies an area of about 29,000 square kilometers. This region presents an extraordinary altitudinal variation, from 500 meters above sea level to elevations exceeding 7,000 meters, encompassing some of the most distinct ecological and human-environment systems on the planet. It is composed of three major physiographic zones: the Great Himalayan range, the Middle Himalaya, and the Lower or Shivalik ranges, each characterized by unique climatic conditions, vegetation types and human settlement patterns. Together, these zones illustrate the intricate ecological gradients that define the Himalaya as a complex socio-natural system, profoundly sensitive to environmental fluctuations and anthropogenic pressures. In the Great Himalayan range, lying above 3,500 meters, perpetual snow and ice sustain the major perennial rivers of northern India, making this zone the hydrological lifeline of the subcontinent. Below this glaciated expanse lies the Middle Himalaya, between 1,000 and 3,500 meters, consisting of alpine pastures, highlands, and mid-altitude valleys. The alpine pasturelands or *Bugyals*, ranging from 2,800 to 3,500 meters, are among the most fragile ecosystems, rich in endemic flora and medicinal plants. The highlands, between 1,800 and 2,800 meters, are dominated by coniferous forests of deodar, oak, spruce, and fir, interspersed with limited agricultural settlements characterized by high agro-biodiversity. Multiple cereal cultivars and horticultural crops such as apples, peaches, almonds, and leafy vegetables have traditionally sustained local livelihoods. Further downslope, the mid-altitude zone (1,000–1,800 meters) supports the densest population and most extensive arable land, where pine forests coexist with fields of wheat, paddy, citrus fruits, and onions. The Lower Himalaya or Shivalik hills, below 1,000 meters, mark the transition to subtropical plains and river valleys, supporting deciduous forests and intensive agriculture with crops such as sugarcane, mango, litchi, and guava. These ecological tiers are united by an interdependent hydrological and climatic system that is, however, increasingly destabilized by anthropogenic climate change.

The climatic regime of the Garhwal Himalaya varies sharply with altitude. Average summer temperatures range from over 26°C in Dehradun to about 7°C in Tungnath, with winter temperatures in the higher altitudes often plunging below freezing. Rainfall, too, displays significant spatial variability, from around 900 mm in Srinagar Garhwal to over 2,200 mm in Dehradun, reflecting the strong orographic influence of the mountain terrain. Yet this climatic diversity also brings hazards: flash floods, landslides, and glacial lake outbursts have become recurrent phenomena, aggravated by deforestation, infrastructure expansion, and erratic precipitation. These hazards have profound social and ecological repercussions, contributing to rural vulnerability and restructuring the region's demographic and land-use patterns. Recent decades have witnessed an accelerating pace of socio-ecological transformation in Garhwal. Improvements in education, infrastructure, and communication networks have stimulated rural-urban migration, fundamentally altering settlement patterns and economic dependencies. With limited livelihood opportunities in subsistence agriculture, younger generations increasingly migrate toward urban centers in search of education and employment. Statistical data reflect this exodus, showing that rural depopulation is widespread, with some villages experiencing more than 50% out-migration. The districts of Tehri and Pauri record the highest levels of migration, followed by Chamoli and

Rudraprayag. In contrast, the plains districts of Dehradun and Haridwar display lower migration rates, partly due to greater economic diversification. A strong correlation emerges between literacy rates and migration patterns. With literacy levels exceeding the national average, especially in Dehradun and the mid-altitude villages studied, education has become a primary driver of socio-economic mobility. However, the consequences of this migration are complex. While it enhances income diversification through remittances, it also leads to land abandonment, loss of traditional farming knowledge, and a gradual decline in agricultural productivity. In the villages of Ali and Nagar Kotiyana, for example, reductions in the area under cereal and fruit crops have been substantial, leading to an overall contraction of local food systems and a decline in livestock numbers. This represents a broader shift from an agrarian to a semi-urban economy, where the ecological landscape is redefined by both climatic stress and socio-economic change. Climate change has further compounded these transitions. Variations in temperature and precipitation have altered cropping zones, reduced per hectare yields, and caused a gradual shift of fruit cultivation toward higher altitudes. Empirical data from several villages across the Kewer Gadhera sub-watershed reveal declines in the area under apple, potato, and citrus cultivation between 1990 and 2014, coupled with a modest increase in paddy and wheat fields.

Such shifts indicate both adaptive and maladaptive responses: while some farmers diversify to cope with climatic uncertainty, the overall agricultural base continues to shrink due to labor shortages and declining soil fertility. The decline of apple cultivation illustrates this transformation vividly. Once a hallmark of the temperate Garhwal region, apple orchards have drastically diminished in both area and productivity. In the 1970s and 1980s, the region's climatic conditions favored high-quality apple production, leading to the demarcation of dedicated fruit belts. Over subsequent decades, however, warmer winters and altered rainfall patterns have degraded the suitability of these zones, forcing apple cultivation to retreat to higher altitudes while simultaneously reducing its economic viability. The result has been a collapse of commercial apple farming, with production now largely restricted to local consumption. Such transformations have cascading socio-ecological consequences. Reduced agricultural productivity contributes to food insecurity, undernutrition, and growing dependence on external food supplies. Forest degradation, declining livestock populations, and changes in land use further destabilize the ecological balance. Meanwhile, the conversion of fertile valley land into commercial and infrastructural zones signifies an ongoing urbanization of the mountain economy. The cumulative outcome is a reorganization of the Garhwal Himalaya's socio-environmental fabric, a process where traditional ecological systems are eroded while new economic and cultural patterns emerge under the twin pressures of globalization and climate stress. In essence, the Garhwal Himalaya encapsulates the broader paradox of mountain development under climate change: while human progress, education, and infrastructural modernization enhance certain aspects of living standards, they simultaneously disrupt the ecological and cultural continuities that have sustained these regions for centuries. Understanding and managing this delicate balance requires an integrative approach that links climatic adaptation, sustainable land management, and social resilience. The future of the Garhwal Himalaya depends not merely on economic modernization but on the ability to harmonize human aspirations with the fragile dynamics of a changing mountain environment.

6. IN CONCLUSION

The Garhwal Himalaya exemplifies the fragile interdependence between climate, ecology, and livelihood systems in high-altitude environments. As climate change accelerates, its impacts on the migration patterns of both wild and domesticated animals are becoming increasingly evident, altering grazing cycles, disrupting habitats, and straining the adaptive capacities of species and communities alike. The once-harmonious rhythm of seasonal movement, which sustained biodiversity and cultural continuity, now faces unprecedented uncertainty due to rising temperatures, erratic rainfall, and the loss of ecological balance. Preserving this intricate system requires more than isolated conservation measures; it calls for an integrated approach that combines traditional ecological knowledge with modern climate adaptation strategies. Only by reinforcing these connections between people, animals, and the environment can the Garhwal Himalaya maintain its resilience amid the challenges of a changing climate.

CONFLICT OF INTERESTS

None.

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