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Squeezed At Both Ends of the Migration: Climate Change, Land Use and Land Cover Change and the Transhumance of the Bakkarwal of Jammu and Kashmir

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ABSTRACT: The Bakkarwal are the principal long-distance nomadic pastoralists of the north-western Indian Himalaya, moving each year between winter ranges in the Shivalik foothills of Jammu and summer pastures above 3,000 m in Kashmir and Ladakh. Their transhumance exposes them to the climate and the land use of three very different landscapes in one annual cycle, yet the evidence on how those landscapes are changing has never been assembled along the migration corridor itself. This paper does so. We harvested published remote-sensing land use and land cover (LULC) change studies, station-based climate trend studies, cryosphere studies and ethnographic and survey research on the Bakkarwal, coded each estimate to the corridor zone in which it lies (winter range, Pir Panjal transit, Kashmir summer range, Ladakh) and standardised LULC change to annual rates. 104 class-level LULC estimates from 15 studies and 134 climate trend values from 29 studies were compiled. Built-up land is expanding in every study (13 of 13 estimates positive, median +4.2% of initial area per year) and horticulture in every Kashmir study (11 of 11 positive, median +1.7% a−1), forest is declining in 16 of 22 estimates, and the grazing-land classes show no consistent direction because valley-floor pasture is being lost while scrub expands on degraded forest. Annual temperature trends are positive in 44 of 45 station values, with night-time warming of +0.3 to +0.8 °C per decade strongest in the Pir Panjal transit zone, and annual precipitation is declining in 16 of 17 station values, most steeply in the summer range. Snow and glacier cover is shrinking in 7 of 8 LULC estimates and by 31% across Jammu and Kashmir since 2000. Survey evidence records a two to three week advance in departure dates, feed supplementation in more than 80% of households and sedentarisation of 14 to 39% of households. Assembled as a seasonal exposure matrix, the evidence shows a system squeezed at both ends: warming and shrinking snow pull the migration earlier while urban and horticultural expansion, fencing and evictions remove the winter range and the unowned transit pastures on which the early season depends. The paper identifies the winter range and the spring ascent, not the alpine pastures, as the segments of the corridor where climate and land-use pressures now coincide, and sets out the data gaps, above all the absence of any LULC change study for Kathua, Samba, Udhampur or Poonch, that must be closed before the corridor can be managed as a whole.

1. INTRODUCTION

Mobile pastoralism in the Himalaya is built on a seasonal contrast. Pastures at high altitude are productive for a few months in summer and buried in snow for the rest of the year, while the foothills and plains are grazeable in winter but hot and dry by late spring. Transhumant herders convert this contrast into a livelihood by moving between the two, and in doing so they depend on the condition of every landscape along the route and on the timing of the seasons that open and close each one. Both are changing. Warming in the north-western Himalaya has exceeded the global mean over the last century (Bhutiyani et al., 2007), winter is shortening and snowfall is giving way to rain (Bhutiyani, 2015; Shekhar et al., 2010), and the foothill and valley landscapes that herders pass through are being built over, fenced and converted to orchards at rates that remote sensing has documented district by district (Alam et al., 2020; Ridwan et al., 2026).

The Bakkarwal (also written Bakarwal or Bakerwal) of Jammu and Kashmir are the clearest case. Recognised as a Scheduled Tribe in 1991 and numbering 113,198 in the 2011 Census alongside 980,654 Gujjars, with whom they share language and much of their economy (Kumar, 2018; Dar and Das, 2023), they keep large flocks of sheep and goats and undertake one of the longest regular migrations in South Asia, up to 600 km on foot between the Shivalik foothills of Kathua, Jammu, Rajouri and Poonch and the alpine meadows of Kashmir and Ladakh (Dar, 2020; Sareen, 2022). A survey by the Tribal Affairs Department in 2021, reported in the press, put the transhumant population at close to 600,000 people of whom about 500,000 still make the biannual journey. Ethnographic work from the 1980s onward described the system in detail (Rao, 1992; Casimir and Rao, 1998; Khatana, 1992), and a recent wave of survey-based studies has recorded how the Bakkarwal perceive climate change and how their livelihoods are shifting (Tufail, 2014; Tufail et al., 2024; Goswami and Rajput, 2024; Rajput and Goswami, 2025).

What is missing is a view of the whole corridor. Climate trend studies are organised by station or by physiographic region, LULC studies by district or watershed, and pastoralist studies by community or by pasture, and none of them asks how the changes line up along the route that a Bakkarwal family actually walks. This matters because the migration is a chain of seasonal windows. A warmer April empties the winter pasture earlier; an earlier departure meets more snow on the passes; a fenced transit slope forces a longer march to the next camp; a converted valley floor removes the staging pasture below the marg. Each of these is documented somewhere in the literature, but the pressures have not been placed side by side against the calendar.

This paper assembles that view. We compile published LULC change statistics, climate trends, cryosphere observations and ethnographic and survey findings for the Bakkarwal corridor, code each to its corridor zone, standardise the LULC changes to comparable annual rates and read the whole against the seasonal migration calendar. Three questions guide the synthesis. First, how do rates of LULC change differ between the winter range, the Pir Panjal transit zone and the summer ranges, and which classes are changing? Second, how do climate trends differ along the same gradient, and in which season is the change concentrated? Third, where along the corridor and in which months do the two sets of pressures coincide with the constraints the Bakkarwal themselves report? The answers do not require new field data, but they do require reading the existing record in a way that no previous study has attempted.

2. THE BAKKARWAL TRANSHUMANCE SYSTEM

The seasonal cycle is well described and consistent across sources. From mid-November to the end of March the herds are at winter bases in the outer Shivalik hills of Jammu province, at 600 to 1,200 m, grazing within a radius of about 10 to 18 km of the camp (Chowdhary, 2024; Ahmed et al., 2023). By late April the winter pastures of Rajouri, Poonch and Kathua are exhausted and the ascent begins, traditionally on the first day of Baisakh around 13 April (Dar, 2020; Tufail et al., 2024). Families cross the Pir Panjal by one of at least seven routes, including Pir ki Gali, Jamiya Gali, Nurpur Gali and the Banihal pass, at 2,100 to 4,100 m (Suri, 2014; Verma et al., 2019; Dar, 2020), and reach their margs and dhoks in late June or early July after 30 to 60 days on the move (Kheraj et al., 2017; Suri, 2014). The summer pastures lie at 3,000 to 4,500 m in the side valleys of Kashmir, at Pahalgam, Sonamarg, Gulmarg, Tosamaidan, Bangus and Gurez, and in Kishtwar, Warwan and Zanskar (Dar, 2020; Verma et al., 2019). The descent begins in late September and the herds are back in Jammu by November, having spent 110 to 130 days of the year walking (Sharma, 2020). Migration counts at six check posts in 2012 recorded 21,886 people and 246,070 animals moving up in one season (Suri, 2014).

Flocks are dominated by goats and sheep, with horses for transport and a few buffalo among the Gujjar households that move with them (Saleem et al., 2024; Warikoo, 2000). Pasture access rests on a layered tenure of owned, leased and lent plots at the summer end, described by Rao (1992), and on customary but unrecorded rights over forest and wasteland in winter. Casimir and Rao (1998) made the observation that frames much of what follows: the plots through which all herders pass on the biannual migration, and which no authority recognises as owned, are the most degraded in the system. The state's role has changed sharply since 2019. The Indian Forest Act and the Forest Rights Act were extended to the Union Territory in 2019-2020, an eviction drive under Section 79A of the Forest Act followed in late 2020, and the administration listed 63,000 encroachment cases on 15,000 ha of forest (Nasir and Bhushan, 2021; Mehmood, 2024; media reports). In 2022 foot movement of herds on the Jammu-Srinagar highway was restricted and 50 trucks were provided to move families instead (media reports). These institutional changes are not climate or LULC change, but they determine how much of the landscape the herds can still use.

3. MATERIALS AND METHODS

3.1 Evidence harvest

Three bodies of literature were searched with the same rule: only values printed in the source were recorded, with the citation and a verbatim quotation or table reference, and nothing was estimated or imputed. The first body is remote-sensing LULC change for any district, watershed, protected area or town on the corridor. Searches combined district and valley names (Kathua, Samba, Jammu, Udhampur, Rajouri, Poonch, Doda, Kishtwar, Ramban, Banihal, Anantnag, Lidder, Sind, Ganderbal, Kupwara, Bandipora, Baramulla, Budgam, Srinagar, Leh, Zanskar) with the terms LULC, land use, land cover and Landsat, and reference lists were followed. Twenty-three studies with printed class areas or percentages were found; government land-use returns and Forest Survey of India district forest cover were recorded for context but not used in the rate analysis because they are not change series from consistent classification. The second body is station-based climate trend analysis for the same landscapes, harvested from the India Meteorological Department's journal MAUSAM, the regional syntheses of Bhutiyani and colleagues and Shekhar and colleagues, the Kashmir University group's station analyses and the most recent multi-station studies (Zaz et al., 2019; Shafiq et al., 2024; Gopikrishnan et al., 2026), together with cryosphere, phenology and extreme-event studies. The third body is ethnographic, survey and policy research on the Bakkarwal, from Rao and Casimir's field work to the 2024-2025 survey papers, supplemented by press reports where they are the only record of a documented event; those are cited as media reports and used only for events, never for trends.

3.2 Corridor zoning and standardisation

Every estimate was coded to one of four zones: the winter range (Jammu, Kathua, Samba, Udhampur, Reasi, Rajouri and Poonch foothills and the Tawi catchment), the transit zone (Pir Panjal range, Banihal, Batote, Bhaderwah, Doda, Ramban and Kishtwar), the Kashmir summer range (the valley and its side valleys) and the Ladakh summer range. Region-wide values were kept separately. For LULC, each printed class was assigned to one of eight functional categories: forest (dense, open and sparse forest, tree cover, vegetation), grazing land (grassland, pasture, meadow, rangeland, scrub and shrub), cropland, horticulture and orchards, built-up, barren and wasteland, snow and glacier, and water. Scrub was grouped with grazing land because it is grazed in winter and because most studies do not separate it from grassland; the consequence is discussed in Section 4.1. For each class and epoch pair with printed start and end areas the annual rate of change was computed as the change divided by the initial area and by the number of years, expressed as per cent of initial class area per year. This is the only calculation performed on published numbers. Estimates printed only as percentages of the study area, with approximate values, or from non-remote-sensing sources were excluded from the rate analysis. Climate trends were recorded as printed, in °C per year or per decade and mm per year, and reduced to a common unit only for display.

3.3 Synthesis

Because the LULC studies differ in sensor, classification scheme, study area and period, their rates are not pooled with weights. Instead we report the median and range of rates by zone and category, count the direction of change across estimates and test consistency of direction with an exact binomial test against equal probability of increase and decrease. Climate trends are summarised in the same way. The three bodies of evidence are then combined in a seasonal exposure matrix: for each phase of the migration calendar (winter residence, spring ascent, summer residence, autumn descent) we list the climate trend evidence, the LULC and institutional evidence and the impacts and responses reported by the Bakkarwal for the landscape occupied in that phase. The matrix is a device for reading the evidence against the calendar; it does not claim causal attribution.

4. RESULTS

4.1 Land use and land cover change along the corridor

104 class-level rate estimates from 15 studies entered the analysis (Table 1, Figure 1). Two patterns are unambiguous. Built-up land increased in every one of 13 estimates (binomial $p < 0.001$), with a median rate of +4.2% of initial area per year and extreme values around Srinagar (8.9 to 129.6 km² between 1980 and 2010; Akhter and Jaybhaye, n.d.) and in the Lidder valley below Pahalgam (13.2 to 76.0 km² between 1980 and 2018; Rashid et al., 2020). Horticulture increased in all 11 estimates, all of

them in the Kashmir summer range, at a median +1.7% a^{-1}, while cropland declined in 8 of 12, a conversion of paddy to orchard that the authors attribute to economic returns and to depleting streamflow (Rashid et al., 2020; Mushtaq et al., 2024). Forest declined in 16 of 22 estimates ($p = 0.05$; median −0.26% a^{-1}); the exceptions are the two south Kashmir studies in which scrub and open forest classes absorb former grassland and cropland. Snow and glacier classes declined in 7 of 8 estimates.

The grazing-land category is the one that matters most to the Bakkarwal and it is the least consistent, with 8 of 18 estimates negative and a median close to zero. The reason is visible in the individual studies. Where the class is valley-floor pasture it is being lost: 2,928 to 816 ha in the central Kashmir valley between 1992 and 2015 (Alam et al., 2020), 6,924 to 4,259 ha in the Dudhganga watershed on the Tosamaidan side between 1991 and 2010 (Sajjad and Iqbal, 2012), 68 to 22 ha of meadow in Leh between 1990 and 2022 (Taqi et al., 2024), and scrub around Jammu city from 4,072 to 2,261 ha between 1989 and 2014 (Sharma and Kaur, 2016). Where the class is scrub or degraded forest it is expanding, as in south Kashmir (Mushtaq et al., 2024) and the Bandipora watersheds (Gull et al., 2022). The remote-sensing record therefore shows the winter and staging pastures that the herds use shrinking while the class totals stay flat, and any synthesis that reads "grassland" as a single category will miss it.

By zone, the winter range shows slower rates than the summer range for every category but the direction is the same: built-up +0.8 to +4.0% a^{-1} around Jammu, in the Tawi catchment and in Rajouri, forest and grassland declining slowly, cropland stable. Rajouri, the only winter-range district with a full four-epoch series, lost 20.7 km^2 of dense forest, 15.9 km^2 of open forest and 13.8 km^2 of grassland between 1990 and 2020 while wasteland gained 28.2 km^2 and built-up 17.9 km^2; the authors name deforestation, road widening, forest fire, agricultural expansion and overgrazing as the drivers (Ridwan et al., 2026). The transit zone is represented by only three studies, but they are telling. At three sites along the Mughal Road in the Hirpora Wildlife Sanctuary dense forest fell from 132 to 98 ha, 240 to 200 ha and 102 to 59 ha between 1990 and 2010, the third site being the one the authors identify as the summer grazing ground of nomads (Ahmad et al., 2015). In the Kishtwar High Altitude National Park, forest and grassland were stable between 1992 and 2020 but snow cover fell from 1,578 to 1,055 km^2 and rocky barren rose from 305 to 822 km^2 (Lahon et al., 2025), which is the signature of a rising snowline rather than of land use. No LULC change study at all was found for Kathua, Samba, Udhampur or Poonch, nor for Doda, Ramban or Bhaderwah outside the park, so half of the winter range and most of the transit zone are undocumented.

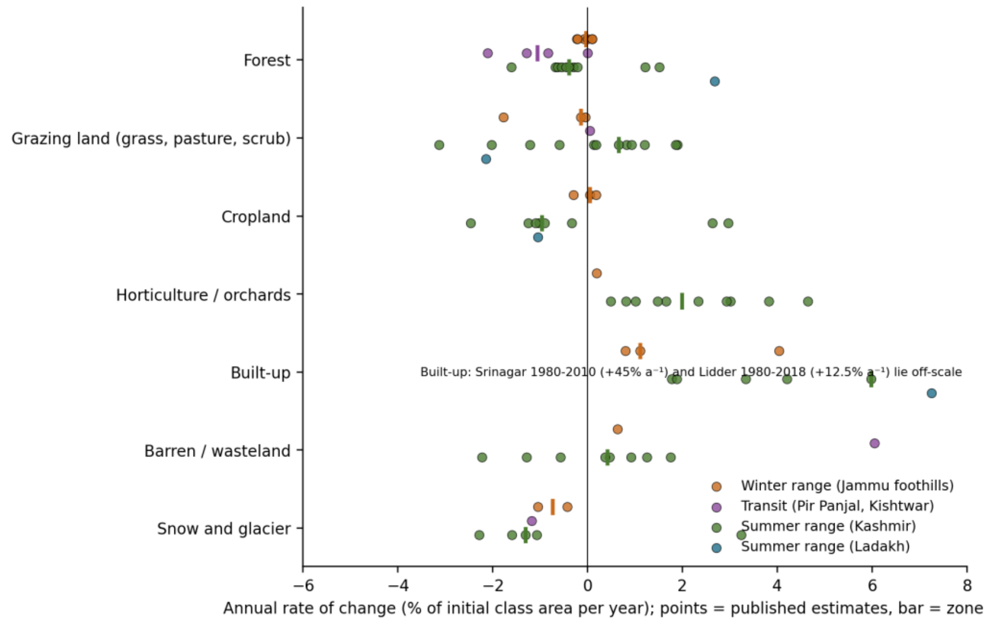

Figure 1. Annual rates of land use and land cover change by functional category and corridor zone, one point per published estimate (per cent of the class's initial area per year); bars mark zone medians. Two built-up estimates lie off-scale to the right.

4.2 Climate trends along the corridor

Table 2 and Figure 2 summarise 45 annual temperature trend values and 17 annual precipitation trend values at stations on or near the corridor. Warming is nearly universal: 44 of the 45 temperature values are positive, and the one exception (Jammu plains maximum temperature, −0.018 °C a^{-1} over 1980-2022; Shafiq et al., 2024) is matched by a separate finding of cooling annual and winter mean temperature at Jammu over 1980-2024 in the most recent IMD-based analysis (Gopikrishnan et al., 2026). The gradient along the corridor is in the night-time temperatures. In the transit zone minimum temperature has risen at +0.3 to +0.8 °C per decade at Batote, Banihal and Bhaderwah, the highest rates in the region and significant in both the 1977-2007 and 1980-2024 analyses (Jaswal and Prakasa Rao, 2010; Gopikrishnan et al., 2026), and pre-monsoon mean temperature at Bhaderwah has risen at about +0.5 °C per decade. In the winter range the picture is also one of night-time warming, +0.5 to +0.6 °C per decade in minimum temperature at Jammu and Katra to 2007 and +0.66 °C per decade across five Jammu province stations to 2020 (Khan et al., 2024), with maximum temperature flat or declining. In the summer range the pattern reverses: maximum temperature is rising fastest, +0.3 to +0.5 °C per decade at Pahalgam, Gulmarg, Kupwara and Kokernag, with a warming of 1.0 to 1.1 °C at Pahalgam and Gulmarg over 1980-2016 and a change point in 1995 (Zaz et al., 2019), while minimum temperature trends are small. Across the region as a whole, warming increases with elevation at 0.18 °C per km per decade (Gopikrishnan et al., 2026).

Precipitation is declining almost everywhere: 16 of 17 annual station trends are negative, the exception being Jammu (+12.05 mm a^{-1}, significant; Jaswal and Prakasa Rao, 2010), where the number of rainy days is nevertheless falling. The decline is steepest in the summer range, with a median of −6.6 mm a^{-1} and a maximum of −16.7 mm a^{-1} at Gulmarg (Zaz et al., 2019), and in the transit zone (−0.9 to −8.5 mm a^{-1} at Banihal, Bhaderwah and Batote). Spring precipitation at Kupwara fell by 42 mm over 1980-2016, and the frequency of western disturbances in November and March has declined while the March precipitation they deliver at Gulmarg and Kupwara has fallen by 3 to 7 mm per month per year (Ahmed et al., 2022). Kathua itself, at the southern end of the corridor, shows no significant trend in monthly, seasonal or annual rainfall over 1990-2024 but a coefficient of variation of 19.5% and a range of annual totals from 785 to 1,886 mm, together with significant warming in August and September and cooling in December (Devi and Gupta, under review). The winter range is therefore not drying on average but is becoming less reliable, while the passes and the summer pastures are both warming and drying.

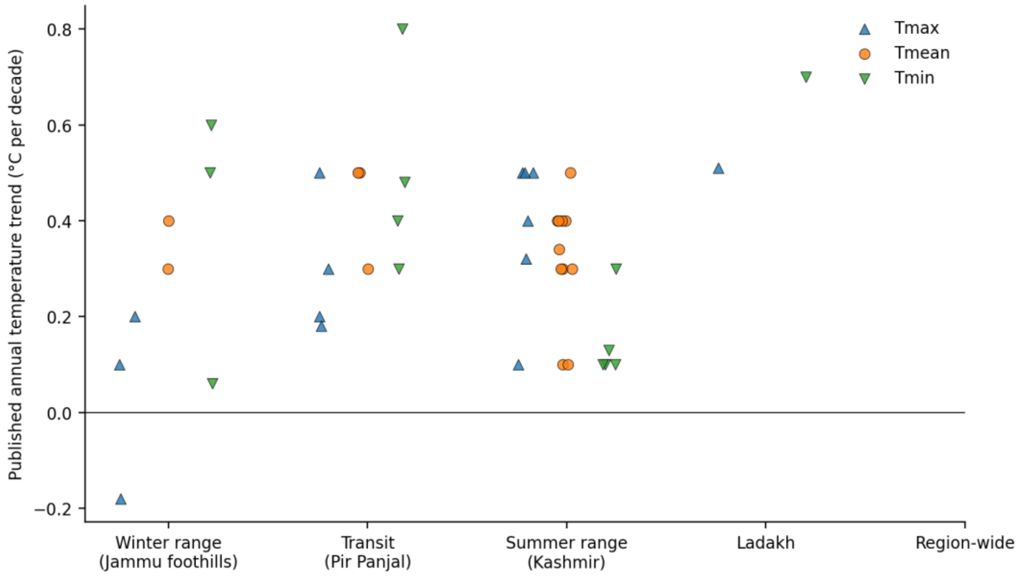

Figure 2. Published annual trends in maximum, mean and minimum air temperature at stations on the Bakkarwal corridor, grouped by corridor zone (°C per decade).

4.3 Snow, glaciers and the growing season

The cryosphere evidence is the most consistent of all. Seasonal snowfall at Pir Panjal stations fell by 280 cm between 1988/89 and 2007/08 while winter maximum and minimum temperatures rose by 0.88 and 0.68 °C (Shekhar et al., 2010); winter has shortened by about two weeks in three decades and a growing share of winter precipitation falls as rain (Bhutiyani, 2015). Snow-covered area in Jammu and Kashmir fell from 22,261 km^2 in 2000 to 15,276 km^2 in 2024, a 31% reduction (Bhat et al., 2025), and the maximum winter snow extent of the Kashmir valley varied between 90% and 50 to 60% of the area in three successive winters (Negi et al., 2009). Glaciers on the Kashmir side of the Pir Panjal and Greater Himalaya lost 28.8% of their area between

1980 and 2018, with small glaciers at 4,200 to 4,400 m, the altitude of the highest pastures, losing about 55% (Romshoo et al., 2020); Kolahoi lost 23.6% between 1962 and 2018 at an accelerating rate after 2000 (Rashid et al., 2020) and the equilibrium line in the Sind basin above Sonamarg rose by 96 m between 1990 and 2018 (Ahmad et al., 2022). Only Zanskar shows a slight increase in snow cover (Khali et al., 2022). At the alpine summits above the pastures, soil temperature rose by 1.5 °C between 2014 and 2018 and species composition shifted towards warm-adapted taxa (Hamid et al., 2020). No study of vegetation phenology or growing-season length for the alpine meadows themselves was found; the nearest evidence is an advance of flowering by 0.6 to 3.0 days per degree in Kashmir woody plants (Hassan et al., 2022).

Extreme events fall in the months when the herds are on the passes. Of 68 cloudburst and heavy-downpour events recorded in Jammu and Kashmir between 2011 and 2022, most occurred between May and August and 40% at 3,100 to 4,100 m (Khan et al., 2025). Between 2010 and 2022 the region recorded 2,863 extreme weather events and 552 deaths, lightning being the most frequent hazard and heavy snow the most lethal per event, with snow deaths concentrated in Kupwara, Bandipora, Baramulla and Ganderbal and flash-flood deaths in Kishtwar, Anantnag, Ganderbal and Doda (Ahmed et al., 2024), all of them summer-range and transit districts. Extreme snowfall in winter and extreme rainfall in summer have both increased in the Pir Panjal over the last 30 years (Bhutiyani, 2016), and the frequency of western disturbances in June has doubled (Hunt, 2024). The consequence for livestock is recorded in the press rather than the literature: the snowfall of 19 to 22 June 2022 killed 1,932 goats, 350 sheep, 80 cattle and 20 horses according to district disaster figures quoted at the time, and the animal husbandry department counted 7,000 sheep lost across Kashmir (media reports).

4.4 What the Bakkarwal report

The survey record is recent and small but consistent. In the largest study, 250 households at five highland pastures in the Pir Panjal and 50 caravans on the Pir Pass and Nandan Sar routes, 72% observed higher summer temperatures, 48% faster snowmelt, 55% less winter precipitation, 70% less monsoon rain, 54% unseasonal snow or hail and 78% more thunderstorms; households reported starting their routes two to three weeks earlier and, in some groups, extending the transhumance period by two to three months (Tufail et al., 2024). Between 80% and 92% of households at each pasture now buy supplementary feed, and 43% to 63% have changed the pasture they use. Earlier work by the same author recorded that 89% of respondents reported declining water from springs, streams and glaciers (Tufail, 2014, as cited in later work). In Poonch, 98% of 58 respondents named shrinking grazing fields as their main problem and 90% had to register with the army before moving (Kheraj et al., 2017). Ethnographic accounts from Kashmir pastures describe fenced pastures, dirt roads for security forces through grazing land and demolition of seasonal huts by the Forest Department (Banka et al., 2025), and studies in Rajouri record changes in herd size and composition, a shift in fodder sources and a move towards mixed or settled livelihoods driven by climate pressure and institutional constraint together (Rajput and Goswami, 2025).

Sedentarisation is the end point. Suri (2014) found that more than 39% of traditionally migratory Gujjar-Bakkarwal had given up migration during the conflict years, with check-post counts falling from about 20,000 to 12,095 persons in one season. Tufail et al. (2024) recorded 14 to 33% of households sedentarised at the five pastures and 86 to 93% seeking alternative income. Dar (2020) found 14 of 40 households semi-sedentarised, citing pasture scarcity, conflict and access to schools and clinics. Chowdhary (2024) found that 65% of respondents wished to settle permanently. At the summer end, the alpine grasslands above 2,500 m in Kashmir are used at 74% of their estimated carrying capacity overall, with overgrazing localised at Thajwas and Mohand Marg (Saleem et al., 2024); the constraint on the system as a whole is not the summer pasture but access to it and to the winter and transit pastures below.

4.5 The seasonal exposure matrix

Table 3 places the three bodies of evidence against the migration calendar. Read by row, it shows that no phase of the cycle is free of pressure, but that the pressures differ in kind. In winter the dominant change is land use: the foothill scrub and grassland within reach of the camps are being built over and fenced, and the climate signal is warmer nights and less reliable rain rather than a trend in totals. In the spring ascent the dominant change is climatic: the passes are warming faster than any other part of the corridor, the snowpack that once held the herds back is thinner, and the herds now leave earlier into a season of increasing cloudbursts and unseasonal snow, across transit slopes that no one owns and that are the most degraded plots in the system. In summer the pasture itself is holding, but its approaches are being converted to orchards and settlements and its use is increasingly policed. In autumn the constraints are institutional: registration, highway restrictions and the truck scheme. The

Bakkarwal responses recorded in the surveys, earlier departure, feed purchase, changing pasture, longer absence and settlement, are each a rational answer to one of these cells.

5. DISCUSSION

5.1 A system squeezed at both ends

The literature on Himalayan pastoralism has tended to look uphill, to the alpine pastures, when it asks how climate change affects herders, and the Karakoram and Himalayan glacier record makes that instinct understandable. The corridor view assembled here points the other way. The alpine grasslands of Kashmir are within carrying capacity and stable in area in every study that maps them; what is disappearing is the winter range in the Shivaliks and the staging and transit pastures between 1,200 and 3,000 m. The winter range is being lost to the fastest-growing towns in the region, Jammu and its satellites, and to the fencing and eviction that followed the extension of forest law in 2019-2020. The transit pastures, degraded because no one owns them (Casimir and Rao, 1998), are the ones that now have to bear an earlier and longer occupation as warming pulls the departure forward. The result is a squeeze from below and from the side rather than from above, and it means that the policy instruments that matter are land-use planning in Jammu province and tenure on the passes, not pasture management on the margs.

5.2 Timing is the mechanism

The climate evidence and the survey evidence converge on timing rather than on totals. Annual rainfall in the winter range shows no trend; what has changed is the minimum temperature, the number of rainy days and the length of winter. The Bakkarwal do not report that the winter pasture has become drier; they report that it is exhausted earlier and that they leave two to three weeks sooner (Tufail et al., 2024). An earlier departure interacts with the transit zone in two ways that the extreme-event record makes concrete. It places the herds on the passes during the weeks when cloudbursts and late snowfalls are most frequent and when lightning deaths peak, and it lengthens the time spent on the unowned transit plots. The June 2022 snowfall, which killed several thousand small ruminants on the move, is the kind of event that a two-week advance in departure exposes more animals to. This is consistent with the loss and damage framing of Goswami and Rajput (2024), in which extreme events produce the economic losses and slow-onset change produces the non-economic ones; our contribution is to show where on the calendar the two meet.

5.3 Reading the LULC record for pastoralists

The grazing-land result carries a methodological lesson. Remote-sensing LULC studies classify scrub, grassland and pasture in ways that suit forest and agricultural monitoring, not pastoral use, and the class totals hide the loss of the specific low-altitude pastures that winter herds depend on behind the expansion of scrub on degraded forest. A study that reports grassland as stable in south Kashmir while paddy is converted to orchard and forest to scrub is accurately describing the landscape and, at the same time, saying nothing about grazing. Studies designed for the pastoral question would separate winter grazing scrub, staging meadows and alpine pasture as classes, would map the corridor rather than the district, and would treat the Kandi belt of Kathua, Samba and Udhampur, for which no change study exists at all, as the first priority.

5.4 Climate and institutions cannot be separated

Every survey-based study of the Bakkarwal in the last decade names climate and institutional constraint together, and the corridor view shows why they cannot be pulled apart. Warming and snowpack loss shorten the season on the winter range; forest fencing and evictions shorten it further by removing the pasture that would have carried the herds through April. Warming lengthens the potential summer season on the margs; demolition of huts and registration requirements shorten the actual one. The adaptive responses that the surveys record, feed purchase, changing pasture, longer absence and settlement, are responses to the combined constraint, and it is not possible from the evidence to say what share of sedentarisation is climatic. What can be said is that the institutional changes since 2019 have removed precisely the buffer, flexible access to foothill forest and to transit slopes, that would have allowed the system to absorb an earlier and more erratic season.

5.5 Limitations

The synthesis inherits the limits of its sources. The LULC studies use different sensors, classification schemes, accuracy standards and study boundaries, and their rates are compared here without weighting because few report class-level uncertainty; the direction counts are robust to this, the medians less so. The corridor zoning is coarse and some studies straddle zones. The winter range and transit zone are thinly covered, with no LULC change study for four of the seven winter-range districts, and the transit zone is represented by two protected areas and one town. Climate trends come from a handful of long-record IMD stations, none of them above 2,700 m, so the passes and pastures themselves are represented by extrapolation from valley stations and by the regional elevation-dependent warming rate. The Bakkarwal survey literature is recent, small in sample and concentrated in the Pir Panjal pastures of Rajouri and Poonch; the Kathua-Kishtwar and Kashmir-Ladakh routes are barely studied. Several livestock-loss events are documented only in the press. Finally, the exposure matrix aligns evidence by season and place; it does not attribute observed livelihood change to any one driver, and no design short of longitudinal household panels along a single route could.

6. CONCLUSIONS

Assembled along the migration corridor, the published record shows a transhumance system under pressure at both ends of its annual cycle. Built-up land is expanding in every landscape the Bakkarwal use, horticulture is replacing cropland and staging pasture throughout the Kashmir summer range, forest is declining in most studies and low-altitude grazing scrub and pasture are being lost around the winter camps even where class totals appear stable. Temperatures are rising at almost every station, fastest at night in the Pir Panjal transit zone and fastest by day in the summer range, precipitation is declining at almost every station and most steeply on the passes and the pastures, and snow and glacier cover has fallen by roughly a third since 2000. The Bakkarwal report the consequences as earlier departure, shrinking winter grazing, purchased feed, changed pastures and a steady drift into settlement. The segment of the corridor where climate and land-use pressure now coincide is the winter range and the spring ascent, not the alpine pastures, and it is also the segment least covered by research. Three steps follow. LULC change should be mapped for the Kandi belt of Kathua, Samba, Udhampur and Poonch and along the transit routes, with classes defined for grazing use. Tenure on the unowned transit pastures, which Casimir and Rao identified as the weak point of the system a quarter of a century ago, should be settled before the earlier and longer occupation that warming is forcing degrades them further. And the migration calendar itself, now moving by two to three weeks, should be built into the timing of forest closures, highway restrictions and the truck scheme, so that institutions adjust to the season rather than fixing a calendar that the climate has already changed.

Data availability

The coding sheets of extracted LULC, climate and ethnographic values, each with source, DOI and verbatim reference, and the script that computes the rates and figures, are available from the authors.

Tables

Table 1. Annual rate of land use and land cover change by functional category and corridor zone: median (n; range) in per cent of the class's initial area per year, computed from printed class areas.

Category	Winter range (Jammu foothills)	Transit (Pir Panjal, Kishtwar)	Summer range (Kashmir)	Summer range (Ladakh)
Forest	-0.04 (n=6; -0.22 to +0.10)	-1.06 (n=4; -2.11 to -0.00)	-0.40 (n=11; -1.61 to +1.51)	+2.68 (n=1; +2.68 to +2.68)
Grazing land (grass, pasture, scrub)	-0.15 (n=3; -1.78 to -0.05)	+0.05 (n=1; +0.05 to +0.05)	+0.66 (n=13; -3.14 to +10.11)	-2.14 (n=1; -2.14 to -2.14)
Cropland	+0.05 (n=3; -0.30 to +0.18)	no estimate	-0.97 (n=8; -2.47 to +2.96)	-1.05 (n=1; -1.05 to -1.05)
Horticulture / orchards	+0.19 (n=1; +0.19 to +0.19)	no estimate	+1.99 (n=10; +0.49 to +4.65)	no estimate
Built-up	+1.11 (n=3; +0.80 to +4.04)	no estimate	+5.99 (n=9; +1.78 to +45.28)	+7.25 (n=1; +7.25 to +7.25)

Barren / wasteland	+0.63 (n=1; +0.63 to +0.63)	+6.06 (n=1; +6.06 to +6.06)	+0.42 (n=8; -2.23 to +1.75)	no estimate
Snow and glacier	-0.74 (n=2; -1.05 to -0.43)	-1.18 (n=1; -1.18 to -1.18)	-1.31 (n=5; -2.28 to +3.24)	no estimate
Water	+0.27 (n=3; -0.72 to +0.49)	+1.20 (n=1; +1.20 to +1.20)	-1.93 (n=6; -2.69 to -0.41)	no estimate

Table 2. Published annual temperature trends (°C per decade) and annual precipitation trends (mm per year) at stations on the corridor, by zone: n, median, range.

Zone	Variable	n	Median	Range
summer range	Tmax	6	+0.45	+0.10 to +0.50
summer range	Tmean	11	+0.34	+0.10 to +0.50
summer range	Tmin	5	+0.10	+0.10 to +0.30
summer range Ladakh	Tmax	1	+0.51	+0.51 to +0.51
summer range Ladakh	Tmin	1	+0.70	+0.70 to +0.70
transit	Tmax	4	+0.25	+0.18 to +0.50
transit	Tmean	3	+0.50	+0.30 to +0.50
transit	Tmin	4	+0.44	+0.30 to +0.80
winter range	Tmax	3	+0.10	-0.18 to +0.20
winter range	Tmean	2	+0.35	+0.30 to +0.40
winter range	Tmin	3	+0.50	+0.06 to +0.60
winter range/transit	Tmax	1	+0.16	+0.16 to +0.16
winter range/transit	Tmin	1	+0.66	+0.66 to +0.66
summer range	Annual precipitation (mm a−1)	11	-6.6	-16.7 to -0.1
transit	Annual precipitation (mm a−1)	3	-7.2	-8.5 to -0.9
winter range	Annual precipitation (mm a−1)	2	+3.3	-5.5 to +12.1
winter range/transit	Annual precipitation (mm a−1)	1	-0.1	-0.1 to -0.1

Table 3. Seasonal exposure matrix for the Bakkarwal migration cycle: published climate, land use and institutional evidence and reported impacts by phase of the calendar.

Phase and landscape	Climate trend evidence	LULC and institutional evidence	Reported impacts and responses
Winter (mid-November to March): Shivalik foothills and Kandi belt of Kathua, Samba, Jammu, Udhampur, Rajouri and Poonch, 600 to 1,200 m	Night-time warming dominates: Tmin +0.5 to +0.6 °C per decade at Jammu and Katra (Jaswal and Prakasa Rao, 2010; Khan et al., 2024); Kathua shows no annual rainfall trend but high interannual variability, CV 19.5% (Devi and Gupta, under review); rainy days declining at all Jammu stations	Built-up area expanding at +0.8 to +4.0% a−1 (Jammu city, Tawi, Rajouri); scrub and grassland declining (Jammu city scrub −1.8% a−1; Rajouri grassland −13.75 km2 1990-2020); forest fencing and Section 79A evictions after 2020	Winter pastures within 10 to 18 km of camps exhausted by late April (Dar, 2020); 98% of Poonch respondents report shrinking grazing fields (Kheraj et al., 2017); demand for supplementary feed in 80 to 92% of households (Tufail et al., 2024)
Spring ascent (April to June): Pir Panjal passes at 2,100 to 4,100 m, Mughal Road, Banihal, Kishtwar	Fastest warming of the corridor: Tmin +0.3 to +0.8 °C per decade at Batote, Banihal and Bhaderwah; pre-monsoon Tmean about +0.5 °C per decade at Bhaderwah (Gopikrishnan et al., 2026); Pir Panjal winter snowfall down 280 cm over 1988/89 to 2007/08 (Shekhar et al., 2010); winter shortened by about two weeks (Bhutiyani, 2015)	Transit plots that no one owns are the most degraded (Casimir and Rao, 1998); Hirpora sanctuary dense forest lost 26 to 42% at three Mughal Road sites 1990-2010 (Ahmad et al., 2015); Kishtwar park rocky barren rose from 305 to 822 km2 as snow cover fell 1992-2020 (Lahon et al., 2025)	Departure advanced by two to three weeks (Tufail et al., 2024); unseasonal June snow in 2022 killed thousands of small ruminants (media reports); cloudbursts concentrated in May to August with 40% at 3,100 to 4,100 m (Khan et al., 2025)
Summer (July to September): alpine pastures (margs, dhoks) of Kashmir at 3,000 to 4,500 m and Ladakh	Annual Tmax +0.3 to +0.5 °C per decade at Pahalgam, Gulmarg, Kupwara and Kokernag; annual precipitation falling at all six Kashmir stations, Gulmarg −16.7 mm a−1 (Zaz et al., 2019); alpine summit soil +1.5 °C 2014-2018 with thermophilisation (Hamid et al., 2020)	Valley-floor pasture lost −1.2 to −1.6% a−1 (Alam et al., 2020; Sajjad and Iqbal, 2012); horticulture expanding at +2% a−1 across ten estimates; built-up +6% a−1; Leh meadows −2.1% a−1; grazing huts demolished and pastures fenced (Banka et al., 2025)	Alpine grasslands above 2,500 m used at 74% of carrying capacity overall but overgrazed at Thajwas and Mohand Marg (Saleem et al., 2024); change of designated pasture by 43 to 63% of households (Tufail et al., 2024)
Autumn descent (late September to mid-November): return through the same passes with 15 to 20 days of grazing on southern slopes	Autumn precipitation declining in Ladakh (Namgyal and Sarkar, 2025); monsoonal western disturbances increasing (Hunt, 2024); late-monsoon (August, September) warming in Kathua (Devi and Gupta, under review)	Foot movement banned on the Jammu-Srinagar highway and replaced by truck transport in 2022 (media reports); registration with the army required by 90% of nomads at check points (Kheraj et al., 2017)	Transhumance period extended by two to three months in some groups (Tufail et al., 2024); sedentarisation of 14 to 33% of households by pasture (Tufail et al., 2024) and 39% after the conflict years (Suri, 2014)

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