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Assessing Socio-Economic Vulnerability to Climate Change in Forest-Fringe Communities: Evidence from Sindh Forest Division, India

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Abstract: The Indian Himalayan Region (IHR) is highly vulnerable to the impacts and variability of climate change. The present study examines fifteen forest blocks across three ranges Sindh, Manasbal, and Harran-Shallabugh within the Sindh Forest Division, with particular consideration of the associated socioeconomic profiles. Six socioeconomic indicators were used to determine socioeconomic vulnerability: population density (km^2), literacy rate (%), percentage of BPL households, percentage of fuel wood consumption, percentage of main workers, and percentage of Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) beneficiaries. The multistage sampling approach was employed to select blocks and ranges, and primary data was collected through field surveys and interactions, using a structured interview schedule. The weight was assigned using a pairwise comparison method (PCM) for the construction of the vulnerability index (VI). Dagapora forest block was the most vulnerable, with VI of 0.774 (1st rank) having socio-economic vulnerability under the present scenario and the Lar forest block had the lowest VI (0.143) indicating that was the least susceptible. Range-wise, the Harran Shallabugh was the most vulnerable with a VI of 0.667 (Ist rank) followed by the Sindh range with a VI of 0.401 (2^{nd} rank), whereas the Manasbal range was the least vulnerable with a VI of 0.344 (3^{rd}). The major drivers of vulnerability across blocks and ranges were high BPL households, fuelwood dependency, rapid population growth, low literacy rates, and a lack of alternative livelihood opportunities, contributing to increased vulnerability. The study highlights the need for targeted adaptation measures, sustainable land management practices, livelihood diversification, and strengthening adaptive capacities to reduce vulnerability and protect forest resources in the region

Keywords: Climate change, Socioeconomic, Forests, vulnerability, Drivers, Adaptation

Climate change has gained significant importance in the global development agenda, owing to its multidimensional impact on economies and human well-being (Musakwa and Odhiambo 2022, Islam 2025, Sharma et al., 2025). Developing nations, whose populations are the most fragile and least likely to adapt readily, would face some of the most severe consequences of climate change (Brenton and Chemutai 2021). These implications jeopardise the capacity to fulfil the 2030 Agenda for Sustainable Development Goals (SDGs) (Singh et al., 2019, Ingutia 2021). According to the World Bank (2007), 25% of the world's poor population rely on forests for their livelihoods, either directly or indirectly. Rural households and communities that depend on forests have close relationships with them, and as a result, derive their economic viability and frequently, their cultural and spiritual identity (Byron and Arnold 2014, Roux et al., 2022). Himalayan forest ecosystems are significant because of the diversity of their flora, fauna, human communities, and cultural practices (Negi 2022). Apart from its significance, it is one of the world's most fragile ecosystems that experience higher levels of climate change impact, with severe consequences for socioeconomic systems (Chakraborty et al., 2010). Climate change has significant negative impacts on mountain ecosystems, particularly in the Indian Himalayan forest ecosystems. Rising temperatures, earlier snowmelt, and changing precipitation patterns alter forest dynamics (Basharat et al., 2016, Hamid et al., 2020). Forest cover decreases with increasing meadow and shrubland cover, which affects biodiversity (Yao et al., 2019). These changes pose significant challenges to biodiversity conservation and the sustainable management of mountain resources in the region (Negi et al., 2017, Wambulwa et al., 2021).

Vulnerability is defined as a function of exposure, sensitivity, and adaptive capability (McDowell and Hess 2012, Segnon et al., 2020). Vulnerability assessments of forests under climate change at the local level are highly relevant for sustainable development (Ordonez and Duinker 2014, Lecina-Diaz et al., 2020). These evaluations provide critical insights into the potential impacts of climate change on forest ecosystems and the communities that depend on them. Such information supports the formulation of adaptive management strategies and informed policy decisions (Brandt et al., 2014, Boulanger et al., 2023, UNDP 2020, Nunes, 2023). This localized approach facilitates the design of targeted adaptation measures that are responsive to specific environmental and socio-economic conditions (Seidl et al., 2011, Sharma et al., 2017a). However, the effectiveness of these assessments in guiding local decision-making can vary, depending on the nature of the data produced and the strength of institutional linkages to policy processes (Greiving et al., 2015). The limited long-term observational data and region-specific assessment frameworks in developing countries like India pose significant challenges to accurately predicting climate vulnerability (Kumar et al., 2018). Assessing the socioeconomic vulnerability of forest fringe communities is a critical priority for informed policy and sustainable forest management (Patt et al., 2012, Reed et al., 2013, Weibhuhn et al., 2018, Darabi et al., 2018). Various approaches have been used to examine the relationships between the socioeconomic factors that influence climate vulnerability throughout the nation (Gopalakrishnan et al., 2021, Kathirvelpandian et al., 2024, Gopalakrishnan et al., 2025). On a regional basis, limited literature is available on the vulnerability assessment of socioeconomic status to climate change. In light of this, the present study aimed to address existing gaps by conducting a realistic assessment of socioeconomic vulnerability in the Sindh Forest Division, with the goal of establishing baseline information on the status of forest fringe communities.

MATERIAL AND METHODS

Study area: The current study was conducted in the Sindh Forest Division, located in the Union Territory of Jammu and Kashmir. This division lies on the geographical coordinates of 34°07'00" to 34°28'00" North Latitude and 74°24'00" and 75°26'00" East Longitude with an area of 37,901 ha (Fig. 1). It comprises three ranges Sindh, Manasbal, and Harran-Shallabugh and fifteen blocks viz; Akhal I, Akhal II, Ganiwan, Gund, Kullan, Kangan Town, Lar, Chattergul, Wangat, Branabugh, Gultibagh, Harran I, Harran II, Dangarpora, and Shallabugh. The altitudinal range varies from 1828.8 meters AMSL near the village of Harran to 5248 m AMSL at the Harmukh peak (Khan et al., 2019). The Sindh Forest Division, is densely populated, primarily by rural communities. The area experiences a mix of temperate and sub-alpine climatic conditions and receives substantial annual precipitation, averaging around 700 mm. Temperature fluctuations typically range from 5°C to 20°C throughout the year. The forests are predominantly composed of Kail (*Pinus wallichiana*), with Fir (*Abies pindrow*) occurring in mixed stands on more exposed sites and Deodar (Cedrus deodara) found in scattered, isolated areas (Banday et al., 2019).

Socioeconomically, the forest-fringe communities of the Sindh Forest Division are predominantly dependent on subsistence agriculture, livestock rearing, wage labour, and forest-based resources such as fuelwood, fodder, medicinal plants, and Non-Timber Forest Products (NTFPs) for their livelihoods. The majority of these households belong to economically marginalised groups with limited access to formal employment, modern agricultural practices, financial services, and healthcare, making them highly vulnerable to external factors. Infrastructure deficits including poor road connectivity, unreliable electricity supply, and inadequate

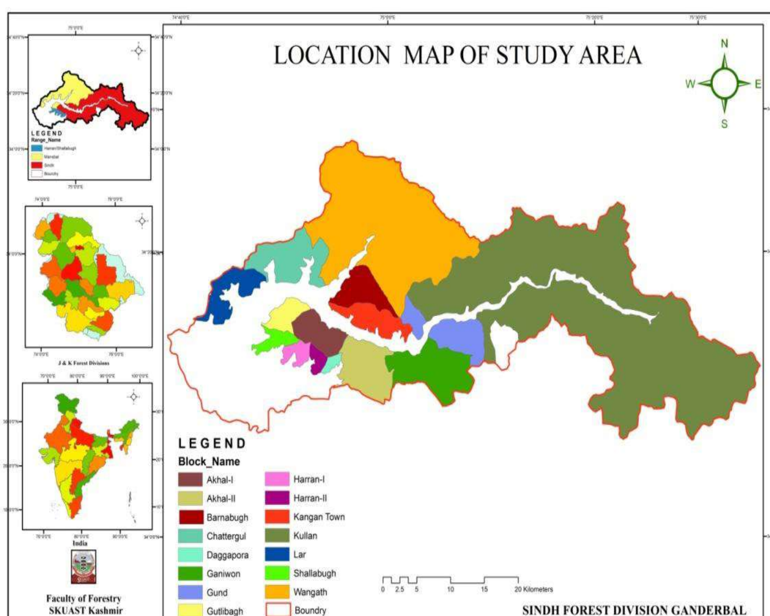

Fig. 1. Location of study area

irrigation facilities further compound their hardship, limiting adaptive capacity and resilience (Hussain 2012, Banday et al., 2021). The region has witnessed a notable rise in temperature an increase of 1.8°C in recent decades (Lone et al., 2022) which has led to erratic precipitation patterns, early snowmelt, and more frequent extreme weather events. These changes have directly affected agricultural productivity, livestock health, water availability, and forest regeneration, thereby undermining traditional livelihoods and increasing dependency on forest resources (Mir et al., 2021). Seasonal migration for employment is also on the rise due to declining on-farm income and resource scarcity (Hussain 2017). In addition, the absence of secure land tenure, limited participation in decision-making, and inadequate implementation of welfare schemes exacerbate the socio-economic fragility of these communities.

Sampling and data collection: The socio-economic vulnerability of forest fringe communities in the Sindh Forest Division was evaluated using an indicator-based approach comprising six key indicators: population density (km^{-2}), literacy rate (%), number of BPL households, percentage of fuel wood consumption, percentage of main workers, and percentage of Mahatma Gandhi National Rural Employment Guarantee Act beneficiaries (MGNREGA) (Table 1). Through a preliminary survey, purposive multistage sampling was conducted, and block- and range-wise samples were collected from the whole forest division. The present study employed a combination of qualitative and quantitative research methods to ensure a comprehensive understanding of the subject. Systematic interview schedules designed for in-depth and direct observations, field surveys and interactions were conducted to collect primary data and Secondary data. Primary data collection involved structured interviews with selected respondents and non-participant observations, following the methodology outlined by (Bernard et al., 2017). These data were collected at both the individual/household and village levels. Meanwhile, secondary data were compiled at multiple levels, including block, village, and household/individual levels, to support the analysis and provide context. Secondary data were obtained from a wide range of sources, including academic journals, research reports, forest department records, village records, internet-based resources, previous studies, annual reports, and other relevant documents from governmental and non-governmental organizations The datasets used in this study are publicly available for download from the following links https://jkforest.gov.in, https://censusindia.gov.in/census.website/, https://fsi.nic.in/forest-report-2023, https://jkfcsca.gov.in/Schemes.html, https://nregastrep.nic.in/ and https:// bhuvan-panchayat3.nrsc.gov.in/. The interview schedule characteristics were derived from the scales designed by (Sharma et al., 2018).

Assigning weights: Each indicator is assigned a weight according to its significance in identifying the vulnerability of the system. The nature and significance of each indicator

Table 1. Indicators, their description, and rationale for their selection for the block and range level analysis

Indicator	Description	Category	Rationale for selection	Function	Weight
Population density (km^{-2})	The number of people living per unit area of land in a forest block or range.	Sensitivity	High population density puts pressure on limited resources, reducing their availability per person. It also increases exposure to environmental risks and disasters.	(+)	0.368
Literacy rate (%)	The percentage of people (aged 7 and above) who can read and write with comprehension	Adaptive capacity	Literacy equips individuals with knowledge and skills to respond to crises effectively, improving disaster preparedness and recovery.	(-)	0.227
Percentage of BPL households	The percentage of households categorized as Below the Poverty Line (BPL).	Sensitivity	A higher share of BPL households indicates economic hardship, making it difficult for communities to adapt to environmental changes.	(+)	0.117
Percentage of fuel wood consumption	The proportion of households primarily dependent on fuelwood for cooking and heating.	Sensitivity	Reliance on fuelwood suggests a lack of access to modern energy sources, often associated with rural communities that have lower resilience.	(+)	0.085
Percentage of main workers	The percentage of people engaged in stable employment for at least six months annually.	Adaptive capacity	A higher employment rate reflects economic stability, ensuring better preparedness and financial security against environmental hazards.	(-)	0.117
Percentage of MNGREGA beneficiaries	The average number of workdays provided per household under the MGNREGA scheme.	Adaptive capacity	MGNREGA offers a financial safety net by providing employment, helping communities sustain their livelihoods during economic hardships.	(-)	0.085

require careful consideration and expert assistance, and the Pairwise Comparison Method (PCM) was used to assign weights to the chosen indicators (Saaty et al., 2008) to ensure that the proportion or weight given to each indication equals one.

Normalization: Normalization is based on a linear maximum and minimum scaling procedure that considers the functional link between indications and vulnerability. Equation (1) has been used to positively connect indicators, that is, those in which vulnerability increases as the indicator's value increases. Equation (2) was employed to establish an inverse relationship between the indicators, specifically in cases where an indicator's increasing value corresponded to a decrease in vulnerability.

$$X_{ij}^{P} = \frac{Xij - Mini\{Xij.}{Maxi\{Xij\} - Mini\{Xij\}} \quad (1)$$

$$X_{ij}^{N} = \frac{Maxi\{Xij\} - Xij.}{Maxi\{Xij\} - Mini\{Xij\}} \quad (2)$$

Where

Xij represents the value of the jth indicator for the ith block/range. That is, Mini{Xij}, which represents the minimum value for the jth indicator of all blocks/ranges, and Maxi{Xij}

Vulnerability index: After multiplying the weight by the normalized indicator value, the results were combined. The following formula was used to aggregate the normalized and weighted values of the indicators to create the overall vulnerability index:

$$VI = \sum_{j} (x_{ij} \times w_j)$$

Where,

VI is the Vulnerability Index. xij are normalized values, and Wj are the assigned weights.

RESULTS AND DISCUSSION

Population density (km^{-2}): Population increase has resulted in high pressure on natural resources. The highest population density of 1387 people per sq. km² was in the Harran I block, indicating that the block places strain on natural resources. Among all forest blocks, Gund had the lowest population density of 90 people per sq. km² (Table 2). The Sindh forest range had the lowest population density among the three ranges, at 241 people per sq. km² (Table 3). Acceleration of population growth has been linked to various forms of environmental degradation, such as the destruction of forests, excessive grazing, deterioration of soil, and depletion of soil nutrients, yielding results comparable to those reported by (Malik et al., 2016, Singh and Yadav 2024).

Table 2. Indicators values of blocks of Sindh forest division

Indicators/Blocks	Population density (km^{-2})	Literacy rate (%)	Percentage of BPL households	Percentage of fuel wood consumption	Percentage of main workers	Percentage of MNGREGA beneficiaries
Akhal 1	164	60.1	0.04	32	6.35	6.93
Akhal II	153	54.18	0.02	33	7.5	6.88
Ganiwon	248	48.97	0.09	39	7.33	6.94
Gund	90	56.85	0.07	42	7.42	7.29
Kullan	160	48.75	0.07	58	7.52	8.09
Kangan Town	636	43.94	0.11	21	8.35	7.98
Lar	143	73.77	0.03	35	7.48	8.51
Chattergul	772	54.91	0.1	31	6.03	7.52
Wangat	201	50.98	0.09	37	7.06	6.35
Branabugh	220	55.1	0.03	29	6.37	6.75
Gutlibagh	455	54.11	0.09	35	6.18	6.68
Harran I	1387	40.61	0.04	15	6.79	6.61
Harran II	1320	40.61	0.04	14	3.98	5.12
Shallabugh	988	52.08	0.03	12	7.31	6.24
Dagapora	1140	38.4	0.1	11	4.21	2.04
Average	538.46	51.55	0.06	29.6	6.65	6.66
Minimum	90	38.4	0.02	11	3.98	2.04
Maximum	1387	73.77	0.11	58	8.35	8.51
Range	1297	35.37	0.09	47	4.37	6.47

Regarding forest commercialization, timber harvesting, and deforestation in Uttaranchal, demonstrating that wood demand increased alongside population growth (Singh et al., 2019). The most landscapes dominated by tropical forests are vulnerable to human-induced disturbances and face potential degradation and loss due to factors unrelated to climate change (Siyum 2020). Sustainable land management practices and increased awareness among populations are crucial for safeguarding resources for future generations (Wairiu 2016, Gupta 2019).

Literacy rate (%): Lar had the highest literacy rate (73.77%), indicating that the block had strong adaptive potential (Table 2), and Dagapora had the lowest percentage (38.4%) (Table 2). The highest literacy rate (57.77%) was in the Manasbal range, indicating that the block has a strong adaptive potential. Among all the ranges, the Harran–Shallabugh range had the lowest percentage (42.94%) (Table 3). Piper et al. (2015) and Seymour and Busch (2016) concluded that regenerated and restored forests with more biodiversity and a multi-tiered forest canopy structure are more resilient to external pressures and improve literacy rates and that lowering poverty rates among families reduces their susceptibility to climate change. (Negi et al., 2019, Mawad et al., 2022) also found a link between extensive forest cover in the IHR, commonly attributed to numerous local governing organizations and schools. Singh et al., (2016) Dulay et al. (2019) also observed that low literacy might be caused by poor socioeconomic situations among parents as well as a lack of educational opportunities. (Leichenko and Silva 2014 , Adeniyi et al., 2018) observed that climate change impacts were unequally felt along gender lines, with illiterate women and, in particular, the elderly being the most vulnerable groups to climate change due to the community's gendered discrimination roles and responsibilities.

Percentage of BPL households: The higher proportion of BPL households suggests a poorer ability to adapt. The maximum number of BPL households was in Block Kangan Town and the Sindh forest range, with 1892 and 6834, respectively (Tables 2, 3), demonstrating that the population has limited adaptive potential. Hahn et al. (2009) observed that, in Mozambique, poor households' livelihood alternatives impact their sensitivity to climate change. (Fisher et al., 2010) also observed that Malawi and low-income families live near forests and are less educated and especially reliant on forests, resulting in lower adaptive ability for forest management. Study conducted in southern Mozambique and South Africa, reported that the vulnerability stems primarily from physical, financial, and social capital, with factors such as food shortages, weak social networks, and a lack of financial resources due to unemployment all influencing households reduced adaptive capacity (Osbahr et al., 2010, Zacarias 2018). This finding emphasizes the importance of adopting livelihood diversification and strengthening adaptive capabilities when developing climate change adaptation strategies.

Percentage of fuel wood consumption: Maximum fuelwood consumption of 58% was in Kullan (Table 3), indicating that the block places a strain on natural resources. Among all the forest blocks, Dagapora had the lowest fuelwood consumption of 11% (Table 2). The Sindh range had the highest value of 37.5%, indicating that natural resources were under severe strain. The Harran Shallabugh forest range had the lowest fuelwood consumption of the three ranges (12.7%) (Table 3). Firewood is the cheapest source of energy in Tanzania, and approximately 90% of the population uses firewood and charcoal for cooking and heating, which negatively affects the forest ecosystems (Felix and Gheewala 2011). Msoffe (2017) reported that the energy balance in Tanzania is dominated by biomass-based fuels, particularly wood fuel (firewood and charcoal), which accounts for more than 90% of the primary energy supply. However, this has led to increased pressure on forest resources, resulting in deforestation and desertification (Mwampamba 2018). Firewood is primarily used at the

Table 3. Indicators values of ranges of Sindh forest division

Indicators/Ranges	Population density (km^{-2})	Literacy rate (%)	Percentage of BPL households	Percentage of fuel wood consumption	Percentage main workers	Percentage of MNGREGA beneficiaries
Sindh	241	52.13	0.42	37.5	7.41	7.35
Manasbal	298	57.77	0.35	33.4	6.62	7.16
Harran	1208	42.94	0.22	12.7	5.57	5
Average	582.33	50.94	0.33	27.86	6.53	6.50
Minimum	241	42.94	0.22	12.7	5.57	5
Maximum	1208	57.77	0.42	37.5	7.41	7.35
Range	967	14.83	0.2	24.8	1.84	2.35

subsistence level, and charcoal production has become more commercialized, potentially posing a greater threat to forest sustainability (Butz 2012). Various approaches have been suggested to address the environmental issues associated with biomass energy consumption. These strategies include enhancing the techniques for producing firewood and charcoal, advocating for the adoption of fuel-efficient stoves, and promoting the utilization of alternative energy resources such as liquefied petroleum gas (LPG) and biogas (Grimsby et al., 2016). Additionally, offering a variety of improved cooking stoves (ICS) and flexible payment mechanisms could increase adoption rates and help reduce fuelwood consumption (Kulindwa et al., 2018). However, it is crucial to consider complex socioeconomic factors and local preferences when implementing these solutions to ensure their effectiveness in conserving forest resources, while meeting the energy needs of the population.

Percentage of main workers: The highest percentage of workers (8.35%) was in Kangan, indicating that the block was easily available for manpower. Among all forest blocks, Harran II had the lowest number of main workers (3.98%) (Table 2). The Sindh range had a maximum (7.41%). The Harran–Shallabugh forest range had the lowest (5.57%) among the three ranges (Table 3). Forest cover in Indian provinces appears to be affected by the peripheral workforce. These activities, along with firewood gathering, may negatively affect the forest cover over time. Consequently, a strategy to reduce forest dependency and expand resources outside of these natural areas could help preserve forest cover and maintain the evolutionary potential of the species. The government has launched Joint Forest Management to boost forest regeneration and rural income. This program could be expanded to address various local issues related to overall village development, potentially enhancing forest cover changes and native species regeneration (Murali et al., 2002). Hofflinger et al. (2021) study in southern Chile demonstrates that the expansion of the forestry industries has not reduced unemployment or improved incomes for indigenous or non-indigenous groups. Instead, they exacerbate the poverty and inequality among these populations. This suggests that the link between forestry employment and socioeconomic outcomes is intricate and may differ based on context (Adams et al., 2016, Malkamaki et al., 2018).

Mahatma Gandhi National Rural Employment Guarantee Act Beneficiaries (MGNREGA): The implementation of MGNREGA suggests a scarcity of alternative employment options, resulting in a reduced adaptive capacity. Significant variations exist among the states during the execution of MGNREGA within the IHR. The highest MNREGA of 8.51% was observed for Lar (Table 2), indicating that the block places a strain on natural resources. Among all the forest blocks, Dagapora had the lowest MNREGA (2.04%) (Table 2), and the Sindh range had the highest MNREGA of 7.35% people per square kilometer, indicating that natural resources were under severe strain. The Harran-Shallabugh

Table 4. Normalized value vulnerability indices (VIs) and corresponding ranks of blocks of Sindh forest division

Indicators/Blocks	Population density(km^{-2})	Literacy rate (%)	Percentage of BPL households	Percentage of fuel wood consumption	Percentage of main workers	Percentage of MNGREGA beneficiaries	VI	Rank
Dagapora	0.81	1.00	0.89	0.00	0.95	1	0.774	1
Harran II	0.95	0.94	0.22	0.06	1.00	0.52	0.615	2
Chattergul	0.53	0.53	0.89	0.43	0.53	0.15	0.509	3
Gutlibagh	0.28	0.56	0.78	0.51	0.50	0.28	0.484	4
Harran I	1.00	0.94	0.22	0.09	0.36	0.29	0.482	5
Wangat	0.09	0.64	0.78	0.55	0.30	0.33	0.448	6
Ganiwon	0.12	0.70	0.78	0.60	0.23	0.24	0.445	7
Kullan	0.05	0.71	0.56	1.00	0.19	0.06	0.428	8
Kangan Town	0.42	0.84	1.00	0.21	0.00	0.08	0.426	9
Gund	0.00	0.48	0.56	0.66	0.21	0.19	0.349	10
Shallabugh	0.69	0.61	0.11	0.02	0.24	0.35	0.337	11
Branabugh	0.10	0.53	0.11	0.38	0.45	0.27	0.307	12
Akhal 1	0.06	0.39	0.22	0.45	0.46	0.24	0.302	13
Akhal II	0.05	0.55	0.00	0.47	0.19	0.25	0.252	14
Lar	0.04	0.00	0.11	0.51	0.20	0.00	0.143	15

forest range had the lowest population density among the three ranges at 5% (Table 3). These findings are related to the diminishment or absence of woodland resources (indicated by forest coverage), which heightens vulnerability through reduced ecological and biophysical adaptive abilities (Lawson et al., 2020). In certain instances, lack of forest cover is an unchangeable geographical feature. Another crucial factor contributing to decreased adaptive capacity, particularly in rural areas, is the prevalence of poverty, which is also a key driver of vulnerability (Wester et al., 2019). In the Hindu Kush Himalaya (HKH), the lack of employment opportunities coupled with other factors has serious implications for the overall development of the region (Mishra et al., 2019). The absence of alternative employment opportunities exacerbates this situation as people are forced to rely on forest resources for their survival, leading to increased deforestation and land degradation (Qasim et al., 2010). In study from the Philippines, irrigation development in lowland areas created new employment options, which subsequently led to reduced forest-clearing rates in upland regions (Shively and Pagiola 2004). This suggests that promoting alternative livelihoods and economic diversification in the HKH region could alleviate forest encroachment while supporting sustainable development. The lack of alternative employment opportunities in the HKH region has significant implications for forest development and conservation. Addressing this issue through integrated approaches that consider economic, social, and environmental factors is crucial for achieving sustainable regional development (Rasul et al., 2017). Policymakers should focus on creating diverse livelihood options, enhancing human capital, and implementing proper and gender-responsive adaptation strategies to reduce vulnerability and protect forest resources in the HKH region (Dilshad et al., 2018).

Vulnerability indices (VIs) of forest blocks and ranges: Composite vulnerability indices lie between 0 and 1, with 0 being the lowest possible vulnerability index and 1 being the highest (Table 5). The Dagapora block had the highest vulnerability index (0.774 (1st rank)), followed by Harran II (0.615) (2nd rank)), indicating that these blocks are more vulnerable. The Lar Forest block had the lowest vulnerability index value of 0.143, indicating that it was less vulnerable, with a vulnerability rank of 15th (Table 4, Fig. 2). The range-wise Harran-Shallabugh range had the highest vulnerability index of 0.667 (Ist rank), followed by the Sindh range of 0.401 (2nd rank), indicating that these are more vulnerable ranges. The Manasbal range had the lowest composite vulnerability index value of 0.344, indicating that it was less vulnerable than the (3rd rank) vulnerability rank (Table 5, Fig. 3). Once sufficient indicators are identified, the vulnerability of each ecosystem can be assessed. Gupta et al. (2019) and Pokhriyal et al. (2020) used various indicators to measure susceptibility throughout the IHR. Sharma et al. (2017b) performed a nationwide vulnerability assessment of India using four vulnerability indicators: biological diversity, disturbance index, forest canopy cover density, and slope. This indicator-based evaluation encompassed the entire country. The same indicators were utilized by (Upgupta et al., 2015) to estimate the vulnerability to the HP condition of the IWH. The current findings are consistent with those of Sharma et al. (2013), investigated the inherent vulnerability of the Aduvalli Forest in the Western Ghats of South India by computing vulnerability indices to evaluate inherent susceptibility and design adaptation strategies.

Major drivers of vulnerability at the block and range levels: The main drivers of vulnerability are identified as indicators with normalized values greater than 0.7 for each block and range, typically resulting in approximately 3-4 primary drivers for each block and range. The major drivers of vulnerability across blocks and ranges were high BPL households, fuelwood dependency, rapid population growth, low literacy rates, and a lack of alternative livelihood opportunities, contributing to increased vulnerability (Figs. 4, 5). Chauhan et al. (2018) also identified climate change-induced disasters, forest fires, overgrazing, over-extraction, and encroachment as primary causes of forest degradation in Uttarakhand. Rotich and Ojwang (2021) concluded that the main factors driving climate change in Kenya's Cherangany Hills forest ecosystem include conversion of forests to croplands and grasslands, grazing, encroachment, illegal logging, firewood harvesting, charcoal production, forest fires, and population growth. Similarly, Debebe et al. (2023) reported that forest cover decline in Northwest Ethiopia was

Table 5. Normalized value of ranges, vulnerability indices (VIs) and corresponding ranks of ranges of Sindh forest division

Indicators/Blocks	Population density(km^{-2})	Literacy rate (%)	Percentage of BPL households	Percentage of fuel wood consumption	Percentage of main workers	Percentage of MNGREGA beneficiaries	VI	Rank
Harran Shallabugh	1	1	0	0	1	1	0.667	1
Sindh	0	0.380	1	1	0	0	0.401	2
Manasbal	0.058	0	0.65	0.834	0.429	0.080	0.344	3

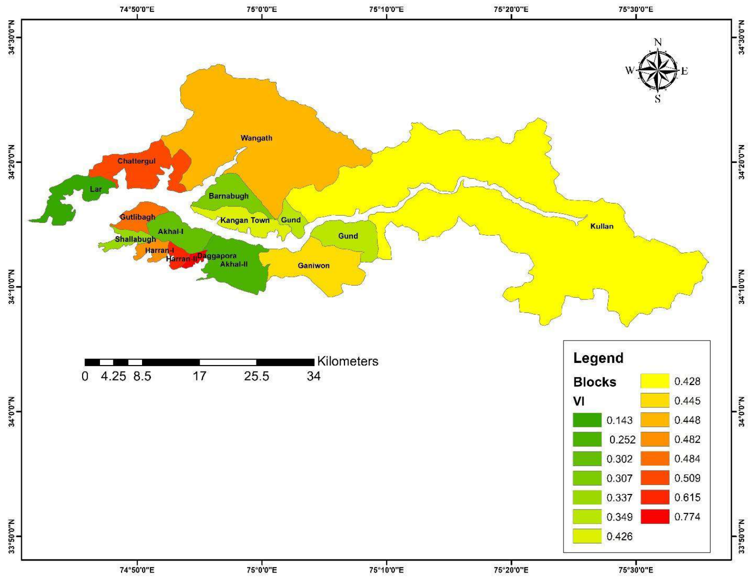

Fig. 2. Block level vulnerability map of Sindh Forest Division

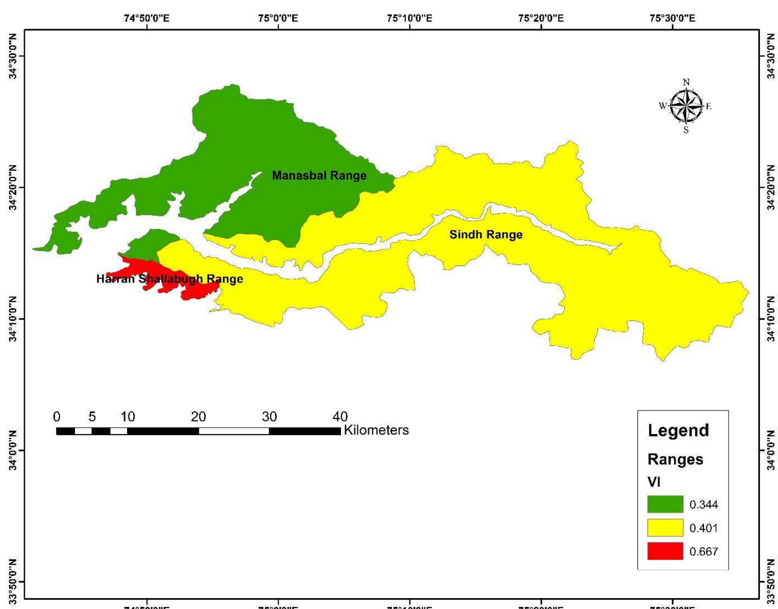

Fig. 3. Range level vulnerability map of Sindh Forest Division

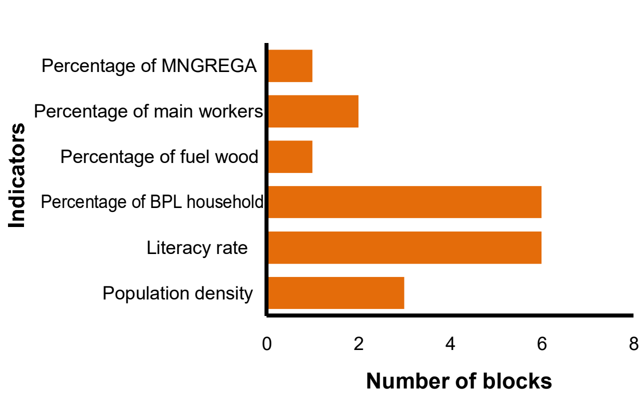

Fig. 4. Key drivers of forest blocks of Sindh Forest Division

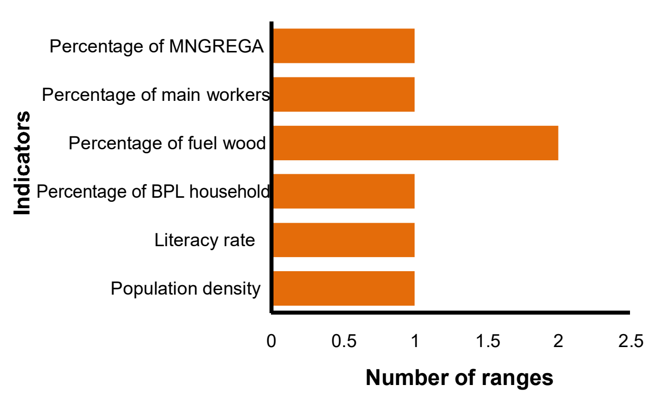

Fig. 5. Key drivers of forest ranges of Sindh Forest Division

driven by agricultural expansion, population growth, growing demand for fuelwood, livestock pressure, and forest fires. Local adaptation strategies have often been overlooked in predicting forest species vulnerability, because they play a more significant role in reducing forest vulnerability under changing climate scenarios (Razgour et al., 2019). The vulnerability of global forest ecoregions to future climate change threatens their biodiversity. Conservation decision making and management may help mitigate climate change-induced forest vulnerability (Wang et al., 2019). Bourgoin et al., (2020) observed the ecological vulnerability of forested landscapes in Vietnam's central highlands and found that multidate satellite data offers promising monitoring capabilities for agricultural and forested landscapes.

CONCLUSION

This study underscores the socioeconomic vulnerability of forest firing communities of Sindh forest division to climate change using six socioeconomic indicators: population density, literacy rate, BPL households, fuelwood consumption, main workers, and MGNREGA participation. The Dagapora forest block was most vulnerable while the Lar forest block was the least vulnerable,. Among the ranges, the Harran Shallabugh was the most vulnerable followed by the Sindh range and the Manasbal range was the least vulnerable . The major drivers of vulnerability across blocks and ranges were high BPL households, fuelwood dependency, rapid population growth, low literacy rates, and lack of alternative livelihood opportunities. Strategies should include afforestation with deep-rooted native species, development of alternative livelihoods for marginalized groups, and integration of poverty alleviation with forest conservation. Promoting income through eco-tourism and Non-Timber Forest Products (NTFP), along with watershed and soil conservation measures, is essential. An integrated resilience plan involving government bodies, civil society, and local communities is vital. Building long-term community resilience calls for a holistic approach that includes progressive policies, legal frameworks, and targeted government schemes. Livelihood diversification through MGNREGA and skill development can reduce forest dependency. Improved food security via the Targeted Public Distribution System (TPDS), along with investments in healthcare and education, supports community stability. Legal frameworks such as the Forest Rights Act (2006) enable forest dwellers to secure traditional rights and benefit from conservation-linked livelihoods. The National Forest Policy (1988) and Joint Forest Management (JFM) promote community participation and equitable benefit-sharing. Selective thinning and fast-growing afforestation for fuelwood help manage forest pressure.

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