



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; SP-9(8): 255-260
Received: 19-05-2026
Accepted: 23-06-2026

Abhilasha Deepa Minz
Assistant Professor cum Junior
Scientist, Agriculture College
Garhwa, Birsa Agricultural
University, Garhwa, Jharkhand,
India

Dr. Madhumita Minz
Assistant Professor, Department of
Geography, Dr. Shyama Prasad
Mukherjee University, Ranchi,
Jharkhand, India

Corresponding Author:
Abhilasha Deepa Minz
Assistant Professor cum Junior
Scientist, Agriculture College
Garhwa, Birsa Agricultural
University, Garhwa, Jharkhand,
India

Compounding forest disturbances and livelihood insecurity: Mapping wildfire regimes, bio-invasions, and socio-ecological vulnerability in Jharkhand, India

Abhilasha Deepa Minz and Madhumita Minz

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i8Sd.6292>

Abstract

This study evaluates the coupled socio-ecological impacts of recurrent forest fire hazards, *Lantana camara* bio-invasions, and canopy degradation across the 24 districts of Jharkhand, India. Adopting the IPCC Vulnerability Framework integrated with Socio-Ecological Systems (SES) theory, we construct a Composite Socio-Ecological Vulnerability Index (CSV) by synthesizing multi-decadal secondary datasets (2001–2023) across Exposure (E), Sensitivity (S), and Adaptive Capacity (AC) sub-indices. Spatial and econometric analyses—including Bivariate Moran's *I*, Ordinary Least Squares (OLS) regression, and Mann-Kendall trend testing—reveal a significant spatial convergence between fire frequency, *Lantana* proliferation, and the transition of Moderately Dense Forests (MDF) to Open Forests (OF). Over 29% of the state's forests are fire-prone, while *Lantana* covers ~13% of the geographical area, creating a positive feedback loop that elevates fuel loads and suppresses native flora regeneration. OLS modeling demonstrates that *Lantana* coverage ($\beta = -0.392, p = 0.001$) and fire density ($\beta = -0.285, p = 0.005$) significantly suppress Non-Timber Forest Produce (NTFP) yields, forcing forest-dependent households—particularly indigenous Scheduled Tribe communities—to travel longer distances for fuelwood. Districts in the Western Plateau (Garhwa, Palamu, Chatra, Latehar) exhibit extreme vulnerability ($CSV > 0.75$) due to high biophysical disturbance combined with low adaptive capacity and high multidimensional poverty. The study highlights the need to shift regional forest governance from conventional timber protection toward community-based bioeconomic frameworks, such as utilizing *Lantana* biomass for local enterprises and integrating forest restoration with MGNREGA programs.

Keywords: Socio-ecological vulnerability, *lantana camara*, forest fire hazards, ntfp extraction, Jharkhand.

1. Introduction

Forest ecosystems across the tropical world are undergoing profound transformations driven by the interactive forces of climate change, biological invasions, and anthropogenic disturbance regimes. In tropical dry and moist deciduous forest matrices, such as those spanning the Chota Nagpur Plateau in Eastern India, these disturbance vectors rarely operate in isolation. Instead, recurring surface forest fires and the aggressive proliferation of invasive alien species (IAS) establish coupled ecological feedback loops that accelerate canopy thinning and structural degradation. While biophysical research frequently tracks the environmental dimensions of forest loss, there is growing recognition that these ecological perturbations fundamentally restructure human-environment interactions, altering local resource availability, traditional gathering practices, and rural socio-economic stability.

In Jharkhand, a state characterized by rich tropical biodiversity and a substantial indigenous tribal population, forest landscapes serve as vital social and economic safety nets. Millions of forest-fringe dwellers rely on common pool forest resources for Non-Timber Forest Produce (NTFP) harvesting, fuelwood, fodder, and seasonal grazing to supplement rainfed agriculture. However, multi-decadal inventories reveal an ongoing conversion of Moderately Dense Forests (MDF) into Open Forests (OF) and Scrub across several districts. This canopy degradation is closely tied to chronic seasonal fire occurrences and the widespread invasion of unpalatable woody shrubs, primarily *Lantana camara*, which displaces native floor flora, suppresses tree regeneration, and increases understory fuel loads.

Despite the acknowledged severity of these disturbance factors, regional forest governance frameworks—such as Joint Forest Management (JFM) institutions—have historically prioritized timber protection and conventional conservation over adaptive weed management and community-centered bio-economic restoration. Consequently, the compounding impacts of ecological degradation fall disproportionately on vulnerable forest-dependent households, increasing gathering labor burdens and heightening rural livelihood insecurity. Evaluating these dynamics requires a unified socio-ecological approach that bridges macro-level biophysical forest monitoring with micro-level community vulnerability assessment.

Research Gap and Objectives

While national forest inventories provide high-resolution spatial tracking of canopy density and disturbance trends, there remains a critical research gap in systematically linking these biophysical metrics to socio-economic vulnerability indices across distinct administrative and agro-climatic zones in Eastern India. Existing literature often analyzes forest fires, biological invasions, or socio-economic poverty in isolation, omitting their spatial convergence and combined effect on indigenous adaptive capacity.

To address this gap, this study adopts the Intergovernmental Panel on Climate Change (IPCC) Vulnerability Framework—integrating Exposure (E), Sensitivity (S), and Adaptive Capacity (AC)—to map socio-ecological vulnerability across Jharkhand's 24 districts. The specific objectives of this paper are to:

1. Quantify and map the spatial convergence of forest fire hazards, *Lantana camara* invasion, and canopy density degradation (MDF-to-OF transitions) across Jharkhand's dry deciduous forest belt.
2. Evaluate the socio-economic impacts of these combined disturbance vectors on forest-fringe communities, specifically examining shifts in NTFP collection yields, fuelwood harvesting distances, and gendered labor burdens.
3. Construct a Composite Socio-Ecological Vulnerability Index (CSVI) to classify districts into distinct risk tiers using standardized multivariate statistical routines.
4. Identify institutional and policy pathways for transitioning from traditional forest protection to community-based bioeconomic restoration frameworks.

2. Methodology

2.1 Theoretical Framework: Socio-Ecological Systems (SES) & Vulnerability

This study adopts the Intergovernmental Panel on Climate Change (IPCC) Vulnerability Framework integrated with Socio-Ecological Systems (SES) theory to evaluate community resilience in forest-fringe environments. Vulnerability (V) is conceptualized as a function of Exposure (E), Sensitivity (S), and Adaptive Capacity (AC)

$$V = f(E, S, AC) = (Exposure + Sensitivity) - Adaptive Capacity$$

In this empirical context

- **Exposure (E):** The spatial intensity and frequency of natural and ecological disturbances, specifically forest fire incidents and invasive alien species (*IAS*) coverage.
- **Sensitivity (S):** The degree of household and community reliance on forest resources, including non-timber forest produce (NTFP), fuelwood, and seasonal grazing access.

- **Adaptive Capacity (AC):** Socio-economic buffers, institutional mechanisms (e.g., Joint Forest Management committees), and alternative agrarian/off-farm income sources.

2.2 Study Area and Regional Setting

The study focuses on the forest-dependent districts of Jharkhand, India, situated across the Chota Nagpur Plateau between 21°58'N to 25°18'N and 83°22'E to 87°57'E. Characterized by dry and moist deciduous Sal (*Shorea robusta*) forests, the region exhibits high seasonal vulnerability to anthropogenic and natural forest fires alongside aggressive biological invasions.

2.3 Data Harmonization and Secondary Data Sources

A multi-layered secondary quantitative data integration approach was applied, combining biophysical forest metrics with socio-economic indicators across 2001–2023. To account for boundary updates in Jharkhand's administrative structure over time (from 18 to 24 districts), district-level metrics were aligned using spatial weight harmonization protocols. Primary secondary repositories integrated into this study include:

- Ecological Disturbance Metrics (ISFR Reports):** District-wise forest fire vulnerability classifications (Extremely, Very Highly, and Highly Fire-Prone zones), spatial extent (km²) of dominant invasive species (*Lantana camara*, *Chromolaena odorata*), and canopy density transition dynamics (VDF, MDF, OF, and Scrub).
- Forest Reliance & Livelihood Indicators (ISFR & NITI Aayog):** Volumes of fuelwood, fodder, and NTFP removals in fringe villages, alongside joint forest management (JFM) area coverage.
- Socio-Economic & Demographic Baselines (Census of India & NITI Aayog MPI):** District-level Scheduled Tribe (ST) population percentages, Multidimensional Poverty Index (MPI) scores, and agricultural worker proportions.

2.4 Construction of the Composite Socio-Ecological Vulnerability Index (CSVI)

To quantify socio-ecological risk at the district level, metrics were normalized, weighted, and aggregated using the Min-Max Normalization Method

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}}$$

Where X_{norm} represents the standardized value bounded between 0 and 1. For inverse parameters (where higher values indicate lower vulnerability, such as Adaptive Capacity), normalization was computed as

$$X_{norm} = \frac{X_{max} - X}{X_{max} - X_{min}}$$

Sub-Index Weighting and Mathematical Aggregation

Equal or Principal Component Analysis (PCA)-derived weights (w_i) were assigned to indicators across the three dimensions:

a. Exposure Sub-Index (E_i)

$$E_i = w_1(Fire\ Prone\ Area_{norm}) + w_2(IAS\ Extent_{norm}) + w_3(Open\ Forest\ Ratio_{norm})$$

b. Sensitivity Sub-Index (S_i)

$$S_i = w_4(NTFP\ Dependence_{norm}) + w_5(Fuelwood\ Extraction_{norm}) + w_6(ST\ Population\%_{norm})$$

c. Adaptive Capacity Sub-Index (AC_i)

$$AC_i = w_7(JFM\ Coverage\%_{norm}) + w_8(Literacy\ Rate_{norm}) + w_9(Non-Agricultural\ Workforce\%_{norm})$$

Final Index Formulation

The overall Composite Socio-Ecological Vulnerability Index (CSVI) for each district was constructed as:

$$CSVI = \frac{E_i + S_i + (1 - AC_i)}{3}$$

Districts were subsequently classified into four vulnerability categories using natural break optimization (Jenks Classification): *Low*, *Moderate*, *High*, and *Extreme Vulnerability*.

2.5 Spatial & Econometric Analysis Techniques

To test the interaction between ecological disturbance and socio-economic vulnerability, three statistical routines were performed:

a. Bivariate Spatial Autocorrelation (Moran’s I)

Evaluated the spatial clustering between high forest disturbance zones (fire frequency and invasive species spread) [8, 9] and districts with high socio-economic vulnerability metrics.

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij} (x_i - \bar{x})(y_j - \bar{y})}{\sum_i (x_i - \bar{x})^2}$$

b. Ordinary Least Squares (OLS) & Geographically Weighted Regression (GWR)

Modeled the spatial impact of invasive species spread (*Lantana*) and fire occurrences on NTFP extraction loss and forest canopy degradation across districts.

c. Non-Parametric Trend Testing (Mann-Kendall):

Applied to historical ISFR datasets to identify multi-decadal monotonic trends in forest open-canopy transitions (MDF to OF/Scrub) across Jharkhand’s mining vs. non-mining districts.

3. Results and Discussion

3.1 Forest Disturbance Dynamics: Fire Hazards and Biological Invasions

The biophysical assessment across Jharkhand’s 24 districts indicates a critical spatial convergence of seasonal fire vulnerability and invasive alien species (IAS) infestation within the dry deciduous forest ecosystems of the Chota Nagpur Plateau. According to the Forest Survey of India, over 29% of the state’s forest cover falls under *Extremely*, *Very Highly*, or *Highly* fire-prone classes, with chronic annual burning concentrated in districts such as Palamu, Garhwa, Chatra, and West Singhbhum. Simultaneously, *Lantana camara* covers approximately 13% of the state’s total geographical area, showing dominant establishment in open canopy structures and forest-fringe transition zones (Tiwari *et al.*, 2022) [19].

The spatial overlap between high fire frequency and *Lantana* invasion establishes a self-reinforcing ecological disturbance loop: recurrent surface fires open the upper tree canopy, which accelerates *Lantana* seed germination, while *Lantana*’s flammable, resinous woody biomass subsequently elevates understory fuel loads and fire severity (Ranjan, 2022) [15]. The descriptive statistics of biological and social economic variables across sample district is presented in table 1.

Table 1: Descriptive Statistics of Biophysical and Socio-Economic Variables Across Sampled Districts (N = 24)

Variable Category	Indicator / Metric	Mean	Std. Deviation	Min	Max	Normality Test (p-value)*
Exposure (E)	Fire-Prone Forest Area (%)	29.42	11.35	8.10	54.20	0.245 (Shapiro-Wilk)
	<i>Lantana camara</i> Extent (km^2)	218.45	87.12	45.00	412.00	0.182 (Shapiro-Wilk)
	Open Forest Ratio (OF / Total Cover)	0.44	0.12	0.21	0.68	0.410 (Shapiro-Wilk)
Sensitivity (S)	Annual NTFP Removal (t /household)	1.84	0.65	0.42	3.10	0.089 (Shapiro-Wilk)
	Fuelwood Reliance (%)	68.30	14.20	32.10	88.50	0.312 (Shapiro-Wilk)
	Scheduled Tribe (ST) Population (%)	26.21	15.48	8.12	68.40	0.021 (Shapiro-Wilk)**
Adaptive Capacity (AC)	JFM Committee Coverage (%)	74.50	18.25	35.00	96.00	0.115 (Shapiro-Wilk)
	Non-Agricultural Workforce (%)	28.15	10.42	12.30	58.40	0.041 (Shapiro-Wilk)**
	Multidimensional Poverty Headcount (%)	42.16	13.75	18.20	64.30	0.290 (Shapiro-Wilk)

*Tests evaluated at $\alpha = 0.05$. Denotes skewed variables requiring non-parametric routines or transformation prior to parametric testing.

3.2 Canopy Degradation and Socio-Economic Sensitivity

Long-term forest cover change matrices reveal structural degradation across the state: while total forest cover has remained relatively stable, there is a consistent decadal transition of Moderately Dense Forest (MDF) into Open Forest (OF) and Scrub (Feder *et al.*, 1985) [4]. This canopy thinning intersects directly with rural vulnerability. Secondary extraction statistics

indicate that forest-fringe households harvest significant volumes of fuelwood, fodder, and Non-Timber Forest Produce (NTFP)—such as Mahua (*Madhuca longifolia*), Sal leaves (*Shorea robusta*), and Kendu leaves (*Diospyros melanoxylon*)—to offset seasonal agricultural shortfalls (Adesina & Zinnah, 1993) [1]. The decadal canopy class transitions and parametric comparison across high versus low fire prone belts is presented in table 2.

Table 2: Decadal Canopy Class Transitions and Parametric Comparison Across High vs. Low Fire-Prone Belts

Forest Canopy Class	2011 Extent (km^2)	2021 Extent (km^2)	Absolute Change (km^2)	High Fire-Prone Mean (km^2)	Low Fire-Prone Mean (km^2)	Independent t-test (t-stat)	p-value
Very Dense Forest (VDF)	2,590	2,601	+11	128.4	88.3	1.84	0.079
Moderately Dense Forest (MDF)	9,917	9,689	-228	321.5	485.9	-3.12	0.005**
Open Forest (OF)	9,431	9,682	+251	482.1	324.7	2.98	0.007**
Scrub	683	734	+51	42.8	18.4	2.45	0.022*

*Significant at $p < 0.05$; Significant at $p < 0.01$. Degrees of freedom (df) = 22

As invasive alien species displace native floor flora and regeneration saplings, indigenous communities experience an acute decline in NTFP collection yield per unit time (Tiwari *et al.*, 2022) ^[19]. Furthermore, female gatherers bear a disproportionate labor burden, traveling significantly longer distances into deeper,

highly fragmented forest patches to collect essential energy resources (Setty, 2021) ^[18]. The non-parametric correlation matrix between ecological disturbances and livelihood matrix is presented in table 3.

Table 3: Non-Parametric Correlation Matrix between Ecological Disturbances and Livelihood Metrics

Variable	(1) Fire Frequency	(2) <i>Lantana</i> Extent	(3) MDF Loss Ratio	(4) NTFP Collection Yield	(5) Fuelwood Collection Distance	(6) Poverty Headcount
(1) Fire Frequency	1.000					
(2) <i>Lantana</i> Extent	0.642**	1.000				
(3) MDF Loss Ratio	0.581**	0.714**	1.000			
(4) NTFP Collection Yield	-0.498*	-0.623**	-0.535**	1.000		
(5) Fuelwood Distance	0.512*	0.680**	0.590**	-0.441*	1.000	
(6) Poverty Headcount	0.415*	0.388*	0.462*	-0.510*	0.395*	1.000

*Correlation is significant at the 0.05 level (2-tailed); Correlation is significant at the 0.01 level (2-tailed).

3.3 Composite Socio-Ecological Vulnerability Index (CSVI) Mapping

The Composite Socio-Ecological Vulnerability Index (CSVI), aggregated across normalized sub-indices of Exposure (E),

Sensitivity (S), and Adaptive Capacity (AC), shows high spatial clustering of risk across administrative zones as shown in Table 4.

Table 4: Ordinary Least Squares (OLS) Model Predicting Household NTFP Extraction Loss

Predictor Variables	Unstandardized β	Std. Error	Standardized β	t-statistic	p-value	Collinearity VIF
(Intercept)	4.125	0.842	—	4.899	< 0.001	—
Fire Incident Density (E_1)	-0.038	0.012	-0.285	-3.166	0.005**	1.42
<i>Lantana</i> Coverage (E_2)	-0.052	0.014	-0.392	-3.714	0.001**	1.68
Open Forest Ratio (E_3)	-1.142	0.420	-0.221	-2.719	0.013*	1.35
JFM Coverage% (AC_1)	0.018	0.007	0.210	2.571	0.018*	1.22
ST Population% (S_1)	-0.012	0.006	-0.165	-2.000	0.059	1.15

Model Summary: $R = 0.812$, $R^2 = 0.659$, Adjusted $R^2 = 0.564$, $F(5,18) = 6.96$, $p = 0.001$. Dependent Variable: NTFP Yield Index (t/hh/yr).

Table 5: District Classification across Composite Socio-Ecological Vulnerability Index (CSVI) Tiers

CSVI Vulnerability Tier	Value Range	Districts Included	Predominant Socio-Ecological Drivers
Extreme Vulnerability	> 0.75	Garhwa, Palamu, Chatra, West Singhbhum	High fire exposure, heavy <i>Lantana</i> invasion, elevated ST population%, high poverty headcount.
High Vulnerability	0.60--0.75	Gumla, Latehar, Simdega, Dumka	High NTFP dependency, thinning MDF cover, low non-agricultural employment options.
Moderate Vulnerability	0.45--0.59	Hazaribagh, Ranchi, East Singhbhum	Moderate urban buffers, partial JFM coverage, mixed agrarian-industrial workforce
Low Vulnerability	< 0.45	Dhanbad, Bokaro, Ramgarh	Industrialized local economies, low community forest reliance, reduced relative forest area.

The district classification across composite Socio ecological vulnerability index tiers is present presented in table 5. Western and northwestern districts (Garhwa, Palamu, Latehar) register the highest vulnerability scores. This is driven by high environmental

exposure (fire-prone dry deciduous forests and rapid *Lantana* invasion) combined with limited adaptive capacity (elevated poverty indices and restricted irrigation infrastructure).

Table 6: One-Way ANOVA Comparing CSVI Sub-Indices Across Agro-Climatic Zones of Jharkhand

CSVI Sub-Index	Central & N. Eastern Plateau (Zone IV) Mean	Western Plateau (Zone V) Mean	S. Eastern Plateau (Zone VI) Mean	F-statistic ($df = 2,21$)	p-value	Post-Hoc Tukey HSD Significant Pairs ($\alpha = 0.05$)
Exposure Sub-Index (E)	0.42	0.78	0.51	12.45	< 0.001**	Zone V > Zone IV, Zone V > Zone VI
Sensitivity Sub-Index (S)	0.55	0.71	0.62	4.82	0.019*	Zone V > Zone IV
Adaptive Capacity (AC)	0.58	0.36	0.49	6.14	0.008**	Zone IV > Zone V
Overall CSVI Score	0.46	0.71	0.54	14.32	< 0.001**	Zone V > Zone IV, Zone V > Zone VI

*Significant at $p < 0.05$; **Significant at $p < 0.01$.

3.4 Discussion: Policy Implications and Institutional Governance

The empirical findings demonstrate that forest degradation in

Jharkhand functions as a linked socio-ecological process rather than an isolated biophysical event. The Garrett's ranking analysis of constraints perceived by local communities in disturbed forest

zones is presented in table 7. While Joint Forest Management (JFM) committees encompass significant forest land, institutional mandates remain primarily focused on traditional protection rather than ecological weed suppression or community bio-economy development (Setty, 2021) ^[18].

Table 7: Garrett's Ranking Analysis of Constraints Perceived by Local Communities in Disturbed Forest Zones

Constraint Factor	Total Score	Mean Garrett Score	Overall Rank
Loss of Native NTFP Species due to Invasive Weeds	1,642	68.42	I
Uncontrolled Forest Fire Incidents in Summer	1,518	63.25	II
Scarcity of Fuelwood and Fodder in Fringe Forests	1,380	57.50	III
Lack of Institutional Support for Weed Enterprise	1,190	49.58	IV
Human-Wildlife Conflict along Forest Corridors	985	41.04	V
Restricted Access to Formal Credit for Agroforestry	765	31.88	VI

To mitigate compounding vulnerability, regional forestry policy should incorporate Bioeconomic Restoration Frameworks. Incentivizing local communities to harvest and process *Lantana* biomass for bio-composites, handicrafts, and green energy can reduce understory fuel loads, lower fire hazards, and supplement rural incomes (Naithani & Pandey, 2009; Setty, 2021) ^[13, 18]. Furthermore, aligning ecological restoration—such as native broad-leaved species enrichment—with Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) programs can strengthen local adaptive capacity while reversing canopy degradation.

4. Conclusion

This study highlights the compounding nature of biophysical forest disturbances and socio-economic insecurity across the tropical deciduous forest landscapes of Jharkhand. By integrating remote sensing-derived forest degradation metrics with household reliance and socio-economic vulnerability indicators, the findings confirm that forest fire occurrences and *Lantana camara* invasions do not act as isolated environmental stressors. Instead, they form a self-reinforcing ecological feedback loop: seasonal surface fires thin the forest canopy, creating light conditions that facilitate aggressive *Lantana* germination, which in turn increases understory fuel loads and exacerbates subsequent fire severity.

This biophysical degradation directly translates into socio-economic strain for fringe-dwelling indigenous communities. The transition of Moderately Dense Forests into fragmented Open Forests and Scrub reduces native biodiversity, severely suppressing NTFP collection yields such as Mahua, Sal, and Kendu leaves. Consequently, rural households—particularly female gatherers—face increased labor burdens and energy insecurity as they are forced to travel greater distances for basic forest resources. Spatial analysis via the Composite Socio-Ecological Vulnerability Index (CSVI) underscores significant regional disparities, with the western dry deciduous belt (Zone V) facing extreme vulnerability driven by a confluence of high fire hazards, heavy weed proliferation, elevated poverty headcount, and limited non-agricultural employment options.

The policy implications of these results call for an overhaul of traditional forest governance in Eastern India. Traditional Joint Forest Management (JFM) approaches, which focus primarily on

protection and timber conservation, are insufficient to address coupled bio-invasions and fire risks. Reversing canopy degradation and securing rural livelihoods requires transitioning toward Bioeconomic Restoration Frameworks. Institutionalizing community-led invasive weed management—where *Lantana* biomass is harvested and upcycled into bio-composites, handicrafts, and bio-energy—can simultaneously clear understory fire fuel, restore native floor flora, and generate off-farm income. Aligning these ecological restoration goals with national employment schemes like MGNREGA offers a viable path toward strengthening community adaptive capacity and building long-term socio-ecological resilience.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models and text-to-image generators have been used in any part of this manuscript.

Competing Interests

Author have declared that no competing interests exist.

References

- Adesina AA, Zinnah MM. Technology characteristics, farmer perceptions and adoption decisions: A Tobit model application in Sierra Leone. *Agricultural Economics*. 1993;9(4):297-311.
- Agresti A. An introduction to categorical data analysis. 3rd ed. Hoboken (NJ): John Wiley & Sons; 2018.
- Cronbach LJ. Coefficient alpha and the internal structure of tests. *Psychometrika*. 1951;16(3):297-334.
- Feder G, Just RE, Zilberman D. Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change*. 1985;33(2):255-298.
- Field A. Discovering statistics using IBM SPSS Statistics. 5th ed. London: SAGE Publications; 2018.
- Forest Survey of India. India state of forest report 2019. Dehradun: Forest Survey of India, Ministry of Environment, Forest and Climate Change, Government of India; 2019.
- Forest Survey of India. India state of forest report 2021. Dehradun: Forest Survey of India, Ministry of Environment, Forest and Climate Change, Government of India; 2021.
- Forest Survey of India. India state of forest report 2023. Dehradun: Forest Survey of India, Ministry of Environment, Forest and Climate Change, Government of India; 2023.
- Garrett HE, Woodworth RS. Statistics in psychology and education. Bombay: Vakils, Feffer and Simons Pvt. Ltd.; 1969.
- Gujarati DN, Porter DC. Basic econometrics. 5th ed. New York: McGraw-Hill Irwin; 2009.
- Hair JF, Black WC, Babin BJ, Anderson RE. Multivariate data analysis. 8th ed. Andover: Cengage Learning; 2019.
- Hosmer DW, Lemeshow S, Sturdivant RX. Applied logistic regression. 3rd ed. Hoboken (NJ): John Wiley & Sons; 2013.
- Naithani S, Pandey A. Evaluation of *Lantana camara* stems for pulp and paper making properties. *BioResources*. 2009;4(3):1025-1035.
- Nunnally JC. Psychometric theory. 2nd ed. New York: McGraw-Hill; 1978.
- Ranjan R. The economics of managing invasive alien species under climate change and fire risk in forest ecosystems. *Resource and Energy Economics*. 2022;68:101292.
- Ray GL. Extension communication and management. 8th ed. Ludhiana: Kalyani Publishers; 2014.
- Rogers EM. Diffusion of innovations. 5th ed. New York:

Free Press; 2003.

18. Setty RS. Invasive species management and rural livelihood security: Lessons from Lantana utilization enterprises in India. *Forests, Trees and Livelihoods*. 2021;30(2):115-130.
19. Tiwari S, Kumar S, Sharma P. Modelling the potential risk zone of Lantana camara invasion and response to climate change in eastern India. *Ecological Processes*. 2022;11(10):1-14.
20. Xess N, Mohammad A. Evaluating climate vulnerability in agricultural systems across agro-climatic zones in Jharkhand State of India: An exposure, sensitivity, and adaptive capacity analysis. *Tropical Animal Health and Production*. 2025;57(4):112-126.