

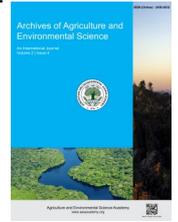


e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes



ORIGINAL RESEARCH ARTICLE



Value chain analysis of *Taxus* (Yew) species and its affecting factors in Makwanpur district, Nepal

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ARTICLE HISTORY

Received: 02 October 2025
Revised received: 09 December 2025
Accepted: 17 December 2025

Keywords

Community forestry
Medicinal and Aromatic Plants (MAPs)
Value Chain Analysis
Sustainable harvesting

ABSTRACT

Taxus, commonly known as Yew, is an ecologically vulnerable but economically valuable medicinal tree widely harvested in Nepal for the production of 10-deacetylbaccatin III (10-DAB III), a key precursor of the anti-cancer drug paclitaxel. Despite its growing commercial importance, systematic assessments of the *Taxus* value chain remain limited. This study analyzes the structure, factor dynamics, governance systems, and economic performance of the *Taxus* value chain in Makwanpur District of Nepal. Using a mixed-method approach, we mapped actor roles, examined costs and margins, and evaluated determinants of value-chain performance. Results showed a strongly hierarchical, buyer-driven chain in which collectors perform the most labor-intensive tasks yet capture less than 5% of final value. Local and district traders mediate quality control, aggregation, and pricing, while processing industries retain the highest value share through technologically intensive extraction of 10-DAB III. Harvesting practices, although largely selective, exhibit inconsistent adherence to sustainable pruning guidelines, posing ecological risks to a slow-growing species with poor natural regeneration. Regression analysis revealed that value chain performance is significantly influenced by timely raw-material availability, farmers' socio-economic conditions, trader education, processing quality, and policy clarity, whereas pre-processing treatment at the household level showed no significant effect. Overall, the study highlights structural inequities, ecological vulnerabilities, and governance bottlenecks within the *Taxus* value chain. Strengthening Community Forest User Group (CFUG) oversight, improving post-harvest handling, enhancing market transparency, and streamlining regulatory procedures are critical for advancing sustainable management while improving livelihood benefits for forest-dependent communities.

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Citation of this article: Devkota, A., Upadhyay, I. K., & Wagle, B. (2025). Value Value chain analysis of *Taxus* (Yew) species and its affecting factors in Makwanpur district, Nepal. *Archives of Agriculture and Environmental Science*, 10(4), 677-686, <https://dx.doi.org/10.26832/24566632.2025.10040x17>

INTRODUCTION

Forest resources underpin rural livelihoods, biodiversity conservation, and national economies throughout the Global South. In Nepal, forests and other wooded land currently cover about 44.74% of the country's land area, reflecting both natural richness and decades of community-based forest management (FAO, 2020; Khanal, 2024; Devkota et al., 2025). Forest resources are the second-richest natural resource base of the

Nepalese economy and provide timber, fuelwood, fodder, and a wide range of non-timber forest products (NTFPs), including medicinal and aromatic plants (MAPs), which are particularly important for rural income generation and serve as safety nets during periods of stress (Bhatt et al., 2021; Ghimire et al., 2021; Khanal, 2024). Forestry sector also contributes 15% of national GDP, generating USD 50.19 million in forest-product revenue over 15 years, including USD 6.91 million from NTFPs/MAPs and USD 37.58 million from protected areas directly and indi-

rectly (Nuberg et al., 2019; Bhatt et al., 2021; Maharjan & Dangal, 2021). At the global scale, the formal forest sector generates more than USD 539 billion in direct value added and over USD 1.3 trillion in total contributions to world GDP and supports more than 18 million direct jobs and over 45 million jobs in total (Li et al., 2020). NTFPs contribute between 9.5% and 40.19% of rural household income across 17 countries, with an average contribution of about 24% (Derebe et al., 2023), while the global medicinal and aromatic plant (MAP) market alone was valued at roughly USD 201 billion in 2023 and is projected to grow from USD 215.4 billion in 2024 to USD 375.6 billion by 2032 (Zamani et al., 2025), underscoring the growing international economic significance of forest and MAP based value chains in which Nepal is increasingly embedded. NTFPs, and especially MAPs, are increasingly recognized as critical for livelihood diversification and green economic development. Nepal hosts more than 1,500 plant species used in traditional medicine, and hundreds are traded domestically and internationally as raw crude drugs or processed ingredients (Ghimire et al., 2021; Bhattarai, 2022). MAPs and NTFPs provide cash income, employment, and conservation incentives, particularly in remote mountain regions where alternative livelihood opportunities are limited (Masoodi et al., 2020; Makkarenu et al., 2025). Globally, the use and trade of MAPs continue to expand. More than 50,000 flowering plant species are used medicinally worldwide, with an estimated 15,000 species threatened by overharvesting, habitat loss, and degradation (Chen et al., 2016; Lorite, 2024). Climate change, land-use conversion, and intensified market integration are placing increasing pressure on wild MAP populations. In Nepal, studies consistently report unsustainable harvest levels, premature collection, selective removal of high-value species, and widespread degradation of alpine and subalpine MAP habitats (Smith-Hall et al., 2025). Also structural weaknesses such as poor governance, weak monitoring systems and limited recognition of customary management practices, information asymmetry, market volatility, and poorly coordinated value chains tend to concentrate benefits among a small number of traders and processors while leaving collectors with low and uncertain returns (Shah et al., 2018; Caporale et al., 2020; Bhattarai, 2022; Singh & Chatterjee, 2022; Chhetri et al., 2024; Smith-Hall et al., 2025).

Among Nepal's medicinal and aromatic plants, *Taxus wallichiana* (Himalayan yew) holds a distinctive and paradoxical status. The genus *Taxus* contains approximately 9–12 species globally and is broadly distributed across the Holarctic region. Core species include *T. baccata* in Europe, *T. brevifolia* in western North America, *T. cuspidata* in Japan and Korea, *T. chinensis* and *T. mairei* in China and Southeast Asia, *T. sumatrana* in parts of Southeast Asia, and *T. contorta* and *T. wallichiana* throughout the Himalayan region (Press et al., 2000). Modern phylogenomic studies further support close evolutionary relationships among Asian *Taxus* species and reveal a complex history of diversification across temperate Asia (Hao et al., 2008; Jia et al., 2022). Additional floristic and systematic treatments also confirm the presence of multiple *Taxus* taxa across Asia and the Himalaya, em-

phasizing variability in morphology, altitude range, and ecological amplitude (Eckenwalder, 2009).

Nepal hosts three native *Taxus* species: *Taxus wallichiana*, *Taxus contorta*, and *Taxus mairei* representing one of the highest concentrations of Himalayan Taxaceae diversity (DPR, 2010). *T. wallichiana* occurs widely between 2,200–3,400 masl from Taplejung to Baglung; *T. contorta* is distributed from Darchula to Gorkha; while *T. mairei* occupies lower hill belts in Makwanpur, Sindhuli, and Kavrepalanchok (DPR, 2010). This diversity highlights Nepal's ecological importance in the global distribution of this genus. *Taxus* species are the exclusive natural source of the anti-cancer drug paclitaxel (Taxol®) and its precursors compounds that revolutionized chemotherapy for ovarian, breast, and lung cancers and continue to play a central role in modern oncology (Gao et al., 2024; Sati et al., 2024). Paclitaxel is a potent microtubule-stabilizing agent that inhibits cell division and has dramatically improved survival rates for several solid tumors (Sati et al., 2024). The global demand for paclitaxel and related taxanes continues to grow, with recent market analyses estimating the paclitaxel injection market at USD 6–7 billion in 2024–2025, with projections exceeding USD 16–20 billion by the early 2030s (Santoyo-García et al., 2023; Sati et al., 2024). Although advances in semi-synthetic and cell culture-based production have helped reduce pressure on wild trees, natural *Taxus* biomass, especially leaves and twigs rich in 10-deacetylbaccatin III (10-DAB III) remains essential to the global taxane supply chain (Santoyo-García et al., 2023; Sati et al., 2024; Coombe-Tennant et al., 2025).

Himalayan yew is native to mid- and high-elevation mixed broadleaf conifer forests across the Himalaya. The species is slow-growing, shade-tolerant, and long-lived, with low natural regeneration and a narrow ecological niche (Mohapatra et al., 2009; Gajurel et al., 2015). Throughout its range, overharvesting, particularly of bark and branches for taxane extraction has led to severe population declines. *Taxus wallichiana* is listed as Endangered in many regional conservation assessments and is a species of concern under multiple national frameworks (CITES, 2016). Extensive studies from India, Nepal, and China report reduced population densities, truncated diameter distributions, and poor seedling recruitment in heavily harvested stands, indicating long-term decline if extraction continues at current levels (Rathore et al., 2019). Climate change further exacerbates these vulnerabilities causing substantial range contractions and altitudinal shifts for *Taxus wallichiana* under future climate scenarios across South and East Asia (Rathore et al., 2019; Li et al., 2020; Zhang et al., 2025; Zhou et al., 2025).

Paclitaxel content varies seasonally, geographically, and among tissues, with leaves often containing commercially significant levels that can be harvested without harming the tree (Das et al., 2023; Santoyo-García et al., 2023). HPTLC-based analyses demonstrate distinctive tissue-specific gradients in paclitaxel concentration and antioxidant activities in Himalayan yew, suggesting the feasibility of targeted, non-destructive harvesting regimes (Das et al., 2023). Meanwhile, advancements in *Taxus* cell culture, metabolic engineering, and bioprocessing continue

to increase extraction efficiency and yield, creating new economic opportunities but also increasing pressure on natural populations (Coombe-Tennant et al., 2025; Santoyo-García et al., 2023; Gao et al., 2024). From a livelihood and policy perspective, understanding the value chain that links *Taxus* leaves, twigs, or extracts to global pharmaceutical markets is essential. Global value chain (GVC) and global production network frameworks emphasize that governance arrangements, power dynamics, and upgrading potential determine who captures value along the chain and under what conditions (Brandt & Thun, 2016; Fernandez-Stark & Gereffi, 2019). In MAP and NTFP value chains, primary collectors typically face information asymmetry, low bargaining power, and high transaction costs, while traders, processors, and downstream pharmaceutical firms often capture disproportionately higher margins (Marshall et al., 2003; Volenzo & Odiyo, 2020).

In Nepal, the commercialization of *Taxus wallichiana* has evolved rapidly over the past three decades. Early studies emphasized propagation trials and conservation risks related to bark harvesting and poor regeneration (Maden, 2003). Subsequent reviews have synthesized the species' pharmacological properties, ecological status, and conservation challenges, highlighting issues such as overharvesting, insufficient monitoring, ambiguous tenure arrangements, and inconsistent regulatory enforcement (Mohapatra et al., 2009). Despite growing international demand for leaf-based raw materials and 10-DAB III, systematic research on the *Taxus* value chain mainly on mapping actors, examining price transmission and margins, understanding governance structures, and identifying bottlenecks remains scarce. Most MAP-focused value chain studies in Himalayas center on species such as *Nardostachys jatamansi*, *Neopicrorhiza scrophulariiflora*, and *Paris polyphylla* (Bista & Webb, 2006; Shah et al., 2018; Singh & Chatterjee, 2022), with *Taxus* mentioned mainly as a vulnerable species rather than as the subject of a dedicated value chain analysis.

This knowledge gap is increasingly problematic given the intersecting pressures of commercialization, conservation risk, and socio-economic dependence. On one hand, the global pharmaceutical sector requires a reliable, cost-competitive supply of paclitaxel and its intermediates (Coombe-Tennant et al., 2025; Sati et al., 2024). On the other hand, Nepal's forest policies aim

to promote sustainable forest management, climate resilience, biodiversity conservation, and equitable benefit-sharing (MoFE, 2018; Khanal, 2024; Smith-Hall et al., 2025). Designing a sustainable *Taxus* value chain for Nepal therefore requires robust evidence on benefit distribution, price dynamics, governance arrangements, and institutional constraints. Against this backdrop, the present study analyzes the value chain of *Taxus wallichiana* in Nepal, focusing on identifying and characterizing the main actors and their functions along the chain; examining price formation, costs, and margins at different stages, with particular attention to collectors and local traders; and assessing governance structures, information flows, and perceived constraints and opportunities for upgrading. By combining field surveys, key-informant interviews, and quantitative value-chain metrics, the study aims to generate evidence that can inform policies and interventions for more sustainable and equitable utilization of Himalayan yew, contributing both to conservation of an endangered medicinal tree and to improved livelihoods in Nepal's forest-dependent communities.

MATERIALS AND METHODS

Study area

This study was conducted in Makwanpur District of Bagmati Province (Figure 1) which is a major harvesting and processing hub for *Taxus wallichiana*. The district covers 2,426 km² and spans 500–2,800 masl, forming a transition from subtropical to temperate forests within the Churia–Mahabharat ecological corridor (MoFE, 2018). Fieldwork focused on Thaha Municipality and Indrasarowar Rural Municipality, which together manage over 14,000 ha of community forests through more than 110 Community Forest User Groups (CFUGs) (DFO, 2023). Community forestry participation exceeds 70% of households, making NTFPs including *Taxus* as an important livelihood source. Makwanpur's strategic role in the national *Taxus* value chain is reinforced by its location along the Tribhuvan Highway and proximity to major buyers such as Dabur Nepal and Evans Life Sciences. Nepal and strong trader networks (CITES, 2016). This combination of ecological suitability, institutional structures, and commercial demand makes Makwanpur an ideal landscape for value chain analysis of *Taxus wallichiana*.

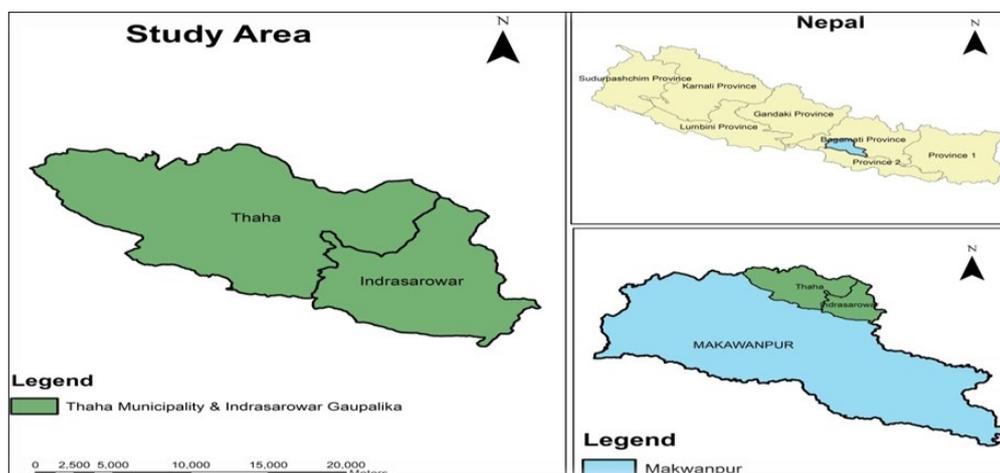


Figure 1. Map of the study area.

Research design and approach

This study applied a mixed-method value chain analysis (VCA) to assess the structure, governance, and performance of the *Taxus wallichiana* value chain. Following established VCA frameworks, the research used a sequential exploratory design, beginning with qualitative scoping through field visits, stakeholder mapping, and informal consultations to identify local harvesting practices, regulatory requirements, and trading relationships. These insights informed the development of structured quantitative tools. Data were collected through household surveys, key informant interviews, and focus group discussions with collectors, traders, CFUG leaders, DFO officials, and industry representatives. Triangulation strengthened the validity of findings. Actor mapping, institutional assessment, and cost–return analysis were used to evaluate the chain across three dimensions: product flows and actor roles, governance and institutional rules, and economic performance, including margins and value addition. This integrated approach provided a comprehensive understanding of how ecological, institutional, and market factors shape *Taxus* commercialization in Makwanpur, Nepal.

Sampling strategy and data collection methods

A purposive and snowball sampling strategy was employed to identify study sites and respondents along the *Taxus wallichiana* value chain in Makwanpur District. Purposive selection of Thaha Municipality and Indrasarowar Rural Municipality which are both major *Taxus* harvesting hubs was guided by their high harvesting intensity and established linkages to processing industries, while snowball sampling enabled identification of additional collectors, traders, CFUG leaders, and officials through referral chains (Noy, 2008). Primary data were collected using reconnaissance surveys, field observations, semi-structured interviews, and focus group discussions, following mixed-method best practices for natural resource and value-chain studies. Interviews with collectors, traders, CFUG office bearers, processing-industry personnel, and Division Forest Office staff provided information on harvesting practices, permit procedures, prices, costs, and governance challenges, while FGDs captured shared experiences and perceptions of sustainability and market functioning. Secondary data from government offices, policy documents, royalty schedules, annual reports, and previous studies were used to triangulate and validate primary findings.

Value chain mapping and analytical methods

Value chain mapping followed established frameworks for agricultural and NTFP commodities, focusing on identifying key actors, product flows, and governance relationships along the *Taxus* chain (Riisgaard et al., 2010). Economic analysis applied standard NTFP value-chain metrics: costs, revenues, gross margins, net margins, and value addition, based on respondent-reported harvesting, transport, and transaction costs (Ingram, 2017). To assess factors influencing value chain performance, a multiple linear regression model was estimated using per-unit net return as the dependent variable and socioeconomic, market access, and institutional variables as predictors, with

diagnostics ensuring model robustness (Gujarati & Porter, 2009). This integrated approach allowed triangulation of economic, institutional, and governance dimensions of the *Taxus* value chain.

Regression model specification

To identify the factors influencing value chain performance, a multiple linear regression model was used with the per-unit net return (NPR/kg) received by *Taxus* collectors as the dependent variable. This approach is widely applied in NTFP livelihood and market studies to quantify the contribution of socioeconomic, market access, and institutional variables to household income outcomes (Belcher et al., 2005; Ingram, 2017). The model was specified as:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_k X_{ki} + \varepsilon_i$$

Where Y_i represents the net return for respondent i , X_{ki}

denotes the explanatory variables, β_k are the parameters to

be estimated, and ε_i is the error term. Explanatory variables included (i) socioeconomic factors (age, education, household size), (ii) market access variables (distance to road, number of buyers, transport cost), (iii) harvesting experience and training, and (iv) institutional factors (CFUG permit type, royalties paid, membership status). Model estimation followed ordinary least squares (OLS), and diagnostic checks including variance inflation factors (VIF), residual plots, and normality tests were performed to ensure reliability and absence of multicollinearity (Gujarati & Porter, 2009). This specification allowed assessment of the relative influence of demographic, economic, and institutional characteristics on the profitability of *Taxus wallichiana* harvesting.

RESULTS AND DISCUSSION

The socio-demographic profile of the respondents showed that *Taxus* collection is primarily a male-dominated activity (71%), although women assist in sorting and drying (29%). In terms of occupation, 27% were engaged in agriculture, 32% in business, 20% in service-related jobs, and 22% were involved in other activities or were unemployed. *Taxus* collection was found to occur from three primary forest regimes: Community Forests, National Forests, and Private Forests (Figure 2a). The largest proportion was sourced from Community Forests, followed by National Forests. *Taxus wallichiana* was primarily harvested from Community and National Forests, whereas *Taxus mairei* was mainly collected from private forest holdings. The amount of *Taxus* collected varied across respondents, with 36% harvesting more than 100 kg (a quintal) each season (Figure 2b). Some collectors did not harvest during the study period because of reduced demand during the pandemic. Seasonally, collection occurred between January and April, concentrating mostly in March–April when weather conditions were favorable (Figure 2c). The trend of *Taxus* collection from 2017 to 2021 is presented in Figure 2d. Collection volumes increased steadily from

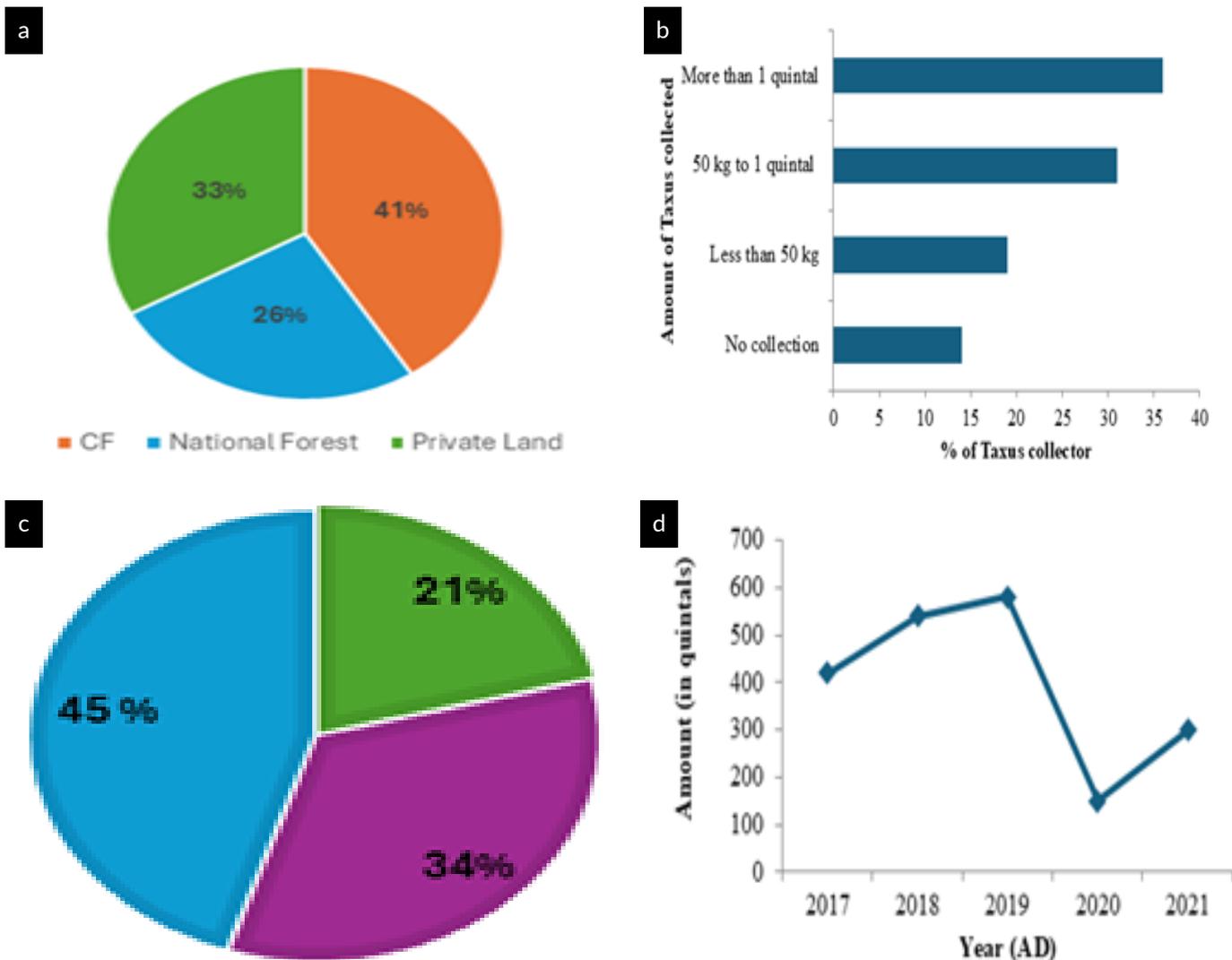


Figure 2. Taxus harvesting characteristics in the study area; (a) Collection regime; (b) Quantity collected per collector; (c) Seasonal harvesting period; (d) Annual trend (2017–2021).

2017 to 2019, reaching nearly 580 tonnes. In 2020, collection dropped sharply following nationwide COVID-19 lockdowns. Collection rebounded in 2021 as processing industries resumed operations and export demand for 10-DAB III increased. Dabur Nepal processed 57% of harvested *Taxus*, followed by Evans Life Sciences (32%), and the remaining 11% by other processors operating both inside and outside the Kathmandu Valley. The final product, 10-DAB III, was primarily exported to India (90%), while the remaining 10% reached other international markets.

Factors involved in *Taxus* value chain and value addition

The *Taxus* value chain in Makwanpur District comprises of collectors, traders, processors, transporters, and regulatory institutions, each contributing distinct roles in harvesting, aggregation, processing, and governance. Collectors are primarily local farmers and CFUG-affiliated households who harvest *Taxus* leaves and twigs during the dry winter months (December–April) when moisture content is lowest. They invest 15–25 days per season, harvesting 150–200 kg of fresh material per household by selectively pruning leafy twigs. Although CFUG guidelines promote non-destructive harvesting, field evidence showed that 17–23% of pruning involved excessive branch removal in areas with weak monitoring or high-income pressure. Such removal of >30–40%

of live crown foliage is known to reduce growth and taxane yield. 62 % of collectors sold fresh leaves directly to traders, while 38% undertook brief sun-drying, though only one-third had appropriate drying surfaces or handling knowledge. Harvesting access is regulated through CFUG permits. 88% of collectors collected *Taxus* leaves and twigs in community forests, while 12% used private lands. Permit fees generally range from NPR 50 to 100 per household, with additional royalties based on collected volume. Monitoring effectiveness varies among CFUGs. Some groups report good compliance, while others experience higher rates of non-compliance. Ecological availability and terrain further shape harvesting intensity. In Indrasarowar Rural Municipality, where *Taxus* density is comparatively high, collectors achieve larger daily harvests with shorter travel distances. In contrast, longer walking distances in lower-density forests of Thaha Municipality reduce yields and increase labor costs. Overall, 56% of collectors described *Taxus* as moderately abundant, while twenty-eight percent noted declines in accessible foliage.

These patterns carry ecological implications. *Taxus* is slow-growing, shade tolerant, and regenerates poorly (Gajurel et al., 2015). Excessive foliage removal can lower shoot growth, taxane concentration, and long-term population viability

(Mohapatra et al., 2009; Sharma & Kala, 2018; Das et al., 2023). Heavily harvested stands across the Himalaya show truncated diameter distributions and low seedling recruitment (Rathore et al., 2019). Spatial variation further influences impacts: harvesting pressure is better distributed in high-density areas but concentrated in low-density forests, slowing regeneration and increasing branch dieback, similar to patterns seen in sparsely distributed Himalayan MAPs. Post-harvest practices such as lack of resin protection elevate risks of fungal infection and dieback (Pandey et al., 2020). Improved CFUG monitoring, training on safe pruning, and rotational harvesting are essential to balance livelihood needs with ecological sustainability. Local traders aggregate small volumes purchased from collectors, conduct basic sorting and drying, and serve as intermediaries to district-level traders based mainly in Palung, Daman, and Hetauda. District traders coordinate bulk purchases, storage, transport logistics, and quality control based on processor requirements. Two main processors; Dabur Nepal and Evans Life Sciences constituted the highest-value node above collectors and traders, extracting 10-DAB III from dried leaves. Their technological capacity and integration with international pharmaceutical markets enable them to set strict quality standards and strongly influence purchase volumes and farm-gate prices. While some extraction occurs domestically, a significant proportion of semi-processed material is exported for advanced purification and final drug formulation. Transporters move *Taxus* biomass from forest sites to market centers and processing facilities using tractors, pickups, and trucks along the Tribhuvan Highway, with transport costs from remote CFUGs significantly affecting trader margins and collector prices. Regulatory and institutional actors including Community Forest User Groups, the Division Forest Office, Department of Forest and Environment, Department of Plant Resource, and CITES authorities that govern harvesting access, royalty collection, sustainability compliance, and international trade regulations.

Price formulation, market channels, and value addition

Price formation in the *Taxus wallichiana* value chain begins with collectors and moves upward through local traders, district-level traders, and processors. Collectors receive NPR 22–28/kg for fresh leaves and NPR 32–38/kg for partially dried leaves, with prices shaped by moisture content, supply volume, and limited bargaining power due to restricted buyer options (processors). Local traders aggregate small daily quantities, perform basic sorting and drying, and resell to district traders at NPR 35–42/kg, earning margins of NPR 5–10/kg. District traders purchase at NPR 40–48/kg, manage storage, transport, quality control, and regulatory compliance, and sell to processors at NPR 55–60/kg. Transport costs comprise 12–18% of trader expenses, reflecting difficult terrain and fluctuating fuel prices. Processors, the highest-value node, extract 10-DAB III for domestic processing or export, and global paclitaxel markets which is projected to exceed USD 193.6 million by 2026. This strongly influence procurement rates (Maden, 2003). When international demand weakens, processors reduce purchase volumes or lower prices,

immediately affecting collector's income. The dominant market channel follows collectors → local traders → district traders → processors → export markets (primarily India). Nepal's prohibition on exporting raw leaves centralizes market power among a few processors, contributing to collectors receiving less than 5% of final product value which aligns with other NTFPs chain marked by information asymmetry and unequal bargaining power (Bista & Webb, 2006; Belcher & Schreckenber, 2007). Information flows remain unidirectional: processors set purchase terms, district traders relay signals, and local traders communicate final offers, leaving collectors without access to wider market information or taxane content requirements. This top-down transmission of price and quality requirements exemplifies a classic buyer-driven governance structure, widely documented in MAP supply chains across the Himalaya (Olsen & Helles, 1997; Sharma & Kala, 2018). Similar dynamics occur in high-value species such as *Nardostachys jatamansi*, *Paris polyphylla*, and *Cinnamomum tamala*, where traders mediate access and capture significant margins (Olsen, 1998). This mirrors global MAP value chains in which industrial processors dominate profit capture through control over extraction technologies and export channels (Santoyo-García et al., 2023; Sati et al., 2024). Across the chain, value addition occurs at each stage. Collector costs include labor which is currently valued at NPR 500–700/day, CFUG permit fees of NPR 50–100, and small transport expenses. With seasonal earnings of NPR 4,000–7,000 (occasionally >10,000 NRS), collectors capture minimal value due to structural disadvantages. Local traders incur costs for purchasing, labor, and short-distance transport, earning NPR 15–20/kg when quality and moisture meet processor standards. District traders add value through bulk aggregation and logistics, earning NPR 10–32/kg depending on transport distance and quality consistency. Processors transform low-value biomass into high-value 10-DAB III, with extraction yields of 533–566 g per ton (CITES, 2016), linking Nepal's *Taxus* chain to a rapidly expanding global oncology market valued at USD 6–7 billion annually and projected to reach USD 16–20 billion by the early 2030s.

Determinants of value chain performance

To identify the factors shaping the performance of the *Taxus wallichiana* value chain, a multiple linear regression analysis was conducted using six predictor variables adapted from the UNEP-WCMC framework of NTFP value chain determinants (Marshall et al., 2003). The factors included Timely availability of *Taxus*, pre-processing treatment, socio-economic situation of farmers, education level of traders, processing quality, and policy environment, with "value chain performance" as the dependent variable (Tables 1-3). The regression model exhibited exceptionally high explanatory power, with an R^2 value of 0.983 indicating that 98.3% of the variation in value chain performance is accounted for by the six predictor variables, leaving only 1.7% attributable to unobserved or random factors. The adjusted R^2 of 0.963 further affirms the robustness of the model by correcting for the number of predictors, suggesting that the

Table 1. Coefficient of variables calculated during the data analysis.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-10.986	5.887		-2.880	0.035
Timely availability of <i>Taxus</i>	2.102	1.511	1.140	2.714	0.042
Preprocessing treatment	4.563	2.305	1.120	2.356	0.065
Socio-economic situation of farmer	6.655	2.870	0.936	3.005	0.030
Education level of Traders	3.197	1.159	1.654	3.946	0.011
Processing quality	3.217	0.957	1.448	3.420	0.019
Policy	6.779	2.673	1.298	3.433	0.019

Table 2. Summary of model used in data analysis.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.991 ^a	0.983	0.963	1.78611

Table 3. Results of ANOVA used in data analysis.

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	13.278	6	2.213	48.108	0.000 ^b
Residual	1.564	34	0.046		
Total	14.842	40			

explanatory strength is not the result of overfitting (Table 2). In applied social-ecological and economic research, an R^2 value above 0.70 is typically considered evidence of a well-fitting model. Therefore, the results collectively demonstrate a highly reliable and statistically sound regression framework for explaining variations in value chain performance. The ANOVA output showed a highly significant model ($F = 48.108$, $p < 0.001$), confirming that the combination of predictors collectively explains a significant proportion of the variance in the dependent variable (Table 3). The extremely small p-value (0.000) rejects the null hypothesis that "all regression coefficients equal zero," demonstrating that changes in predictor variables meaningfully influence value chain performance at the population level (Table 3).

Regression

The coefficient estimates provide insight into the magnitude and direction of each factor's influence: The regression coefficients provide insight into the relative influence of each factor. Timely availability of *Taxus* had a positive and statistically significant effect ($B = 2.102$, $p = 0.042$), showing that consistent raw-material supply stabilizes prices and reduces delays, a pattern also highlighted in broader NTFP research (Ingram, 2017). The socio-economic situation of farmers was another significant predictor ($B = 6.655$, $p = 0.030$), reflecting how better-resourced households are more capable of adhering to proper harvesting techniques, undertaking partial drying, accessing market information, and negotiating more favorable terms. This finding aligns with global NTFP studies demonstrating that socioeconomic capacity enables households to capture greater value within product chains (Angelsen et al., 2014). Trader education level was also significant ($B = 3.197$, $p = 0.011$). Traders with higher education tend to maintain accurate records, navigate regulatory processes more effectively, and meet processor-defined quality standards, contributing to improved procurement efficiency and more stable market relationships. Processing quality likewise had a strong positive influence ($B = 3.217$, $p = 0.019$). Since extraction efficiency and taxane yield depend heavily on leaf

moisture, cleanliness, and uniformity, higher-quality processing translates directly into improved value chain performance. This relationship echoes findings from pharmaceutical MAP systems where biochemical potency and post-harvest handling strongly influence buyer preferences and price formation (Santoyo-García et al., 2023; Sati et al., 2024). The policy environment also showed a strong positive effect ($B = 6.779$, $p = 0.019$), demonstrating that clear regulations, predictable permit procedures, transparent royalty systems, and consistent enforcement significantly improve coordination and reduce transaction costs. Regulatory uncertainty has long been recognized as a constraint in Nepal's NTFP sector, and the present findings reinforce this dynamic. In contrast, pre-processing treatment, although positively associated with performance, was not statistically significant ($B = 4.563$, $p = 0.065$). This reflects the biological and market structure of *Taxus*, where most meaningful improvements in drying, grading, and cleaning occur at industrial processing facilities rather than at the household level. Similar patterns have been documented for other low-perishability Himalayan MAP species where early-stage processing contributes little to final value (Bista & Webb, 2006; Badola & Aitken, 2003). Overall, the results demonstrate that value chain performance is shaped by a combination of supply stability, socioeconomic capacity, trader knowledge, processing quality, and regulatory clarity. Strengthening these areas offers the most effective pathways for improving efficiency, equity, and sustainability within the *Taxus wallichiana* value chain.

Governance and institutional constraints

Governance of the *Taxus wallichiana* value chain in Makwanpur District operates through a multilayered institutional system involving Community Forest User Groups, the Division Forest Office, local governments, provincial agencies, and national regulatory bodies. Together, these institutions influence access to harvesting sites, permit issuance, royalty determination, monitoring, and compliance with national NTFP policies. Despite this structure, governance effectiveness varies widely

across communities, resulting in inconsistent enforcement, uneven benefit distribution, and periodic ecological risks. CFUGs function as the primary regulatory authority. They issue seasonal collection permits, set local royalty rates, define harvesting guidelines, and in some cases impose spatial or temporal restrictions. Field evidence, however, shows variation in monitoring capacity. Some CFUGs reported strong compliance, while others acknowledged gaps that allowed unsustainable harvesting such as excessive removal of larger branches or repeated harvesting from the same forest patches. Because *Taxus* is slow-growing and regenerates poorly, governance weaknesses have particularly serious ecological consequences. At the district level, the Division Forest Office provides regulatory oversight by approving collection and transport permits, verifying royalty payments, and enforcing national forest regulations, including restrictions on the export of raw *Taxus*. Traders and CFUG representatives frequently reported delays in permit processing, ambiguity in required documentation, and inconsistent enforcement at forest checkpoints. These bureaucratic inefficiencies increase transaction costs and create uncertainty, especially for small collectors and traders with limited financial capacity. Local governments, including municipalities and rural municipalities, are still developing their roles in NTFP governance under Nepal's federal restructuring. While some municipalities support training programs or convene NTFP-related meetings, most lack clear guidelines or effective mechanisms for coordination with CFUGs or the DFO. At the national level, agencies such as the Ministry of Forests and Environment, the Department of Forests and Soil Conservation, and the Department of Plant Resources regulate NTFPs through species-specific guidelines for collection, trade, and export. *Taxus wallichiana* receives particular attention due to its conservation status and international demand for taxane-based pharmaceutical compounds. Nepal's ban on exporting raw leaves and bark, allowing export only after processing into intermediate products like 10-DAB III, aims to promote domestic value retention and curb overexploitation. Traders, however, noted inconsistent enforcement of these rules, with shifting interpretations at different checkpoints leading to transport delays and increased costs. Compliance with CITES documentation requirements adds further administrative burden, especially for small traders unfamiliar with technical procedures. Governance challenges are further intensified by structural power imbalances within the value chain. Complex institutional arrangements, uneven enforcement, limited coordination among local and national agencies, and the dominance of buyer-driven market structures collectively constrain the effectiveness of governance and diminish local value retention. While CFUGs and government bodies provide an essential regulatory foundation, more consistent monitoring, streamlined administrative procedures, and clearer institutional coordination are necessary to ensure ecological sustainability and equitable benefits across the chain.

Conclusion

This study provides a comprehensive assessment of the *Taxus*

value chain in Makwanpur District, revealing a system characterized by high ecological sensitivity, strong market asymmetries, and uneven institutional performance. Collectors form the foundational tier of the chain but capture less than five percent of total value despite substantial labor investment and ecological risk. Value addition is concentrated downstream among traders and processors, reflecting a buyer-driven structure in which price signals, quality standards, and market opportunities flow from processors to producers. Ecological assessments show that harvesting pressure, inconsistent pruning practices, and limited technical training threaten the long-term sustainability of *Taxus* populations, especially in low-density stands. These findings underscore the need for more coordinated monitoring, improved harvesting guidelines, and accessible training programs. Regression analysis identified timely resource availability, socioeconomic capacity, trader education, processing quality, and regulatory clarity as key determinants of value chain performance. Strengthening these factors can enhance efficiency, reduce transaction costs, and support more equitable benefit distribution. Governance challenges—including inconsistent CFUG monitoring, administrative delays, variable enforcement of transport and royalty rules, and the complexity of national regulatory procedures that further constrain market confidence and ecological stewardship. To improve value chain outcomes, policy interventions should prioritize strengthening CFUG capacity, streamlining permit processes, improving coordination between local and national institutions, and expanding training on sustainable harvesting and quality handling. Encouraging cooperative marketing and transparent price information systems would enhance bargaining power for collectors. Ensuring ecological sustainability while improving rural livelihoods will require integrated strategies that recognize the biological limitations of *Taxus*, the economic motivations of harvesters, and the institutional complexities shaping access and trade. By addressing these interconnected challenges, the *Taxus* value chain can be transformed into a more equitable, resilient, and environmentally sustainable system.

ACKNOWLEDGEMENTS

Authors thank Prof. Baram Bhatta, AFO Nabaraj Pudasaini, and all local participants including private forest owners, community forest members, and traders for their support and cooperation during this study. We also acknowledge the assistance of MoITFE staffs and Evans Life Sciences throughout the study.

DECLARATIONS

Author contribution statement: Conceptualization: A.D.; Methodology: A.D.; Software and validation: A.D., B.W. and I.K.U.; Formal analysis and investigation: A.D.; Resources: A.D.; Data curation: A.D.; Writing—original draft preparation: A.D., B.W. and I.K.U.; Writing—review and editing: A.D., B.W. and I.K.U.; Visualization: A.D. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Ethics approval: This study did not involve any animal or human participant and thus ethical approval was not applicable.

Consent for publication: All co-authors gave their consent to publish this paper in AAES.

Data availability: The data that support the findings of this study are available on request from the corresponding author.

Supplementary data: No supplementary data is available for the paper.

Funding statement: Not applicable.

Additional information: No additional information is available for this paper.

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