PREDICTING THE POTENTIAL DISTRIBUTION, TRADE, AND CONSERVATION OF *RAUVOLFIA SERPENTINA* IN NEPAL

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Abstract. The main aim of the study was to predict the potential distribution, trade, and conservation of *Rauvolfia serpentina* in Nepal. We used 117 well-dispersed species occurrence points to run the Maximum Entropy (MaxEnt) model with bioclimatic, topographic, vegetation-related, and anthropogenic variables. Twenty-four percent of Nepal's total land area is a potential habitat for *R. serpentina*. The potential area of *R. serpentina* in the protected area is 5,230.92 km^2 (15%). The accuracy of the model was excellent with an average Area Under the Receiver Operating Characteristic Curve (AUC) of 0.92±0.004 with an average True Skill Statistics (TSS) of 0.62±0.03. Nepal's Siwalik region is the best suitable habitat, followed by Terai and Middle Mountain. It is slightly suited in the High Mountains, and it is completely unsuitable in the Himalayas. The increasing price of *R. serpentina* was a good indication for commercial cultivation (average annual increment of price = 0.39%). Based on the scores obtained, the more suitable area (core Terai) showed the highest threat. The trade of *R. serpentina* is very minimal in Nepal due to government restrictions and international laws (IUCN and CITES). Cultivation practices are the major key activities that lead to protecting this species in the natural environment.
Keywords: *Rauvolfia serpentina, distribution, trade, threat, cultivation*

Introduction

Rauvolfia serpentina is known as the Indian Snakeroot plant, belonging to Apocynaceae family, distributed in tropical zones of America, Africa, India, Sri Lanka, Myanmar, and Nepal (Mukherjee et al., 2020). The Indian Subcontinent region has shown greater diversity, particularly around the Gangetic plains. In Nepal, its distribution stretches from east to west up to an altitude of 900 m asl (Kunwar, 2019). *R. serpentina* is primarily found in Nepal's Terai region, where it has been reported up to elevations of 1300-1400 m (Dey and De, 2011). *R. serpentina* can be found in Africa and America's tropical regions, as well as the tropical Himalayas, India, Sri Lanka, Myanmar, Malaysia,

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and Indonesia. It can be found in Nepal's tropical and subtropical regions from east to west at elevations of 100–900 meters (Hara et al., 1979; GoN, 2007). *R. serpentina* is a perennial undershrub that grows in moist, shaded areas of newly regenerated forests. *Shorea robusta, Terminalia chebula, Terminalia bellerica, Asna Terminalia alata, Dalbergia sissoo, Acacia catechu,* and *Adina cordifolia* are the major associated tree species of *R. serpentina* (GoN, 2000). Sarpagandha is an important Ayurvedic drug used for treating many diseases, including high blood pressure. *R. serpentina* is the genuine source plant for Sarpagandha and it is a critically endangered species belonging to the family Apocynaceae (Sulaiman et al., 2021). Therefore, *R. serpentina* is an important medicinal plant widely used in the pharmacological industry for formulating various drugs and medicines (Bharti et al., 2020). *R. serpentina* is used for snake, insect and animal bites, psychosis, schizophrenia, hypertension, blood pressure, gastrointestinal disorders, circulatory disorders, pneumonia, fever, malaria, asthma, skin diseases, scabs, eye diseases, spleen diseases, natural immunodeficiency syndrome, rheumatism, and body aches (Chaudhary et al., 2016).

Review of Literature

Rauvolfia serpentina (Indian snakeroot) is a potential source of phytopharmaceuticals for the treatment of insomnia and is known for its therapeutic uses and the production of traditional beverages (Paul et al., 2022). *R. serpentina* is an indigenous medicinal herb of Nepal having multiple influences on the environment, biodiversity, rural economy, health, and culture. Apart from its traditional use in health care and culture, it has been increasingly used in pharmaceutical industries in the country as well as abroad. Herb Production and Processing Company Limited (HPPCL), Gorkha Ayurveda Company Limited, Dabur Nepal, and Singha Darbar Vaidhyakhana are the major buyers in the country (Tiwari et al., 2004). As per the Forest Rules and Regulations of 1995, the government has established the royalty of NRs. 0.2/kg on the collection of roots from the wild (GoN, 2005b). The government royalty for the dried root of *R. serpentina* is US$ 0.44 per kg. Herb production and processing companies pay US$ 0.88 per kg. Similarly, Gorkha Ayurvedic Company pays US$1.33 per kg. In European countries like Germany, its roots are sold at US$ 3.26 per kg (Acharya, 2007).

According to the World Health Organization report (2021), about 65% of the world's total population uses medicinal plants for curing diseases through their traditional practitioners. Habitat specificity, population size, distribution range, and use patterns play a crucial role in the identification of the status of the species. Population assessment and habitat monitoring using standard ecological methods are urgently required to develop an appropriate strategy for conserving and managing all rare and endangered species and their habitats (Arya et al., 2017). In this context, it is necessary to formulate a strategy for maximizing the benefits of forest resources through their effective utilization. Trading of forest resources and products that have contributed to local employment prospects and national revenue is critical in this setting (Rai and Chapagain, 2014).

R.serpentina species does have an extremely poor germination rate of only about 10%. The success rate of root cutting is approximately 50%. On the other hand, the root stump method is quite effective and produces 100% outcomes, but only one plant may be produced by a stump (Anon, 1969). *R. serpentina* has been included in the IUCN's endangered list due to poor traditional methods of propagation (Chauhan, 1999). Roots are widely marketed due to their high alkaloids, and people harvest roots, which causes them to become endangered in natural habitats (Paul et al., 2022). While harvesting

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R. serpentina, overharvesting is a serious issue that leads species to decline in their natural habitat. As a result, the IUCN has classified this species as endangered, and it is listed in Appendix II of the Convention on International Trade in Endangered Species (CITES) (State, 2017). The government of Nepal has made it illegal to export *R. serpentina* without first processing in Nepal. The export of this species without processing is also banned by Nepal's forest act of 1993 and forest regulation of 1995. The Ministry of Forest and Soil Conservation, Department of Plant Resources, Kathmandu, Nepal, has also included national priority species for cultivation and trading (DPR, 2012).

This species has so far been reported from 17 districts (Banke, Bardia, Chitwan, Surkhet, Gorkha, Kanchanpur, Bara, Parsa, Dhanusa, Morang, Dang, Nawalparasi, Jhapa, Sindhuli, Sunsari, Sarlahi and Kailali) (ESON, 2009). It is used even for minor health issues, though it is valuable and an endangered plant species (Kunwar, 2019). *R. serpentina* has been categorized as an endangered species based on the IUCN threat categories and as critically endangered in the CAMP workshop (Bhattarai et al., 2002). It is listed in CITES Appendix II. The Nepal government has banned its export as a crude drug. It can be exported in processed form with permission from the Department of Forest (GoN, 2005b). It is one of the prioritized medicinal plants of Nepal for research and commercial cultivation (GoN, 2005a). The market price of *R. serpentina* is US$ 12/Kg in Nepal. Only 500 kg of dried roots were collected from the Terai regions of Nepal which were used as the raw materials for Nepal`s Ayurvedic companies (DOF, 2021). The Government of Nepal (GON) has also prioritized *R. serpentina* for commercial cultivation. Farmers of the Terai region of Nepal have been cultivating this species for the past many years. Cultivation in the potential areas protects this endangered species from extinction including the economics of small farmers (DOF, 2021). It was observed that the plant traders could not sell the product because the premature collection was done by rural healers, and caused massive depletion in the distribution of the species. There is very limited research on *R. serpentina in Nepal.* Therefore, this paper predicts the possible habitat distribution including other trade and conservation-related issues. The research analyzed the ecological distribution, trade, and conservation of *R. serpentina* in Nepal.

Materials and Methods

Study area

This research was carried out in Nepal (26.3470 to 30.4730 N and 80.0600 to 88.2040 E), where its elevation varies from 59 m to 8848.86 m (Mount Everest) (Department of Survey, 2020) (*Figure 1*). Annual average precipitation is lowest (271.4 mm) in Jomsom and highest (5514.7 mm) in Lumle. According to the data available from 1980 to 2010, the average temperature in Nepal is 10.9 °C in Jomsom and the highest (24.6 °C) in Janakpur (Department of Hydrology and Meteorology, n.d.). It includes several ecological domains, and is one of the 36 global biodiversity hotspots in the eastern Himalayas, with a total area of 147,516 km^2 (Myers et al., 2000; Ministry of Forest and Soil Conservation, 2014, 2009).

Occurrence points collection

A total of 117 different geographic points were recorded in such a way that each point is at least 1 km apart (*Appendix Table* 1). Possible geographic locations have been identified from various literature sources and direct field visits. The abundance of *R.*

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serpentina is found in the lowlands of the Terai region of Nepal. The occurrence points were randomly selected according to literature and information from DFOs staff, rangers, foresters, and forest guards of Terai, Nepal.

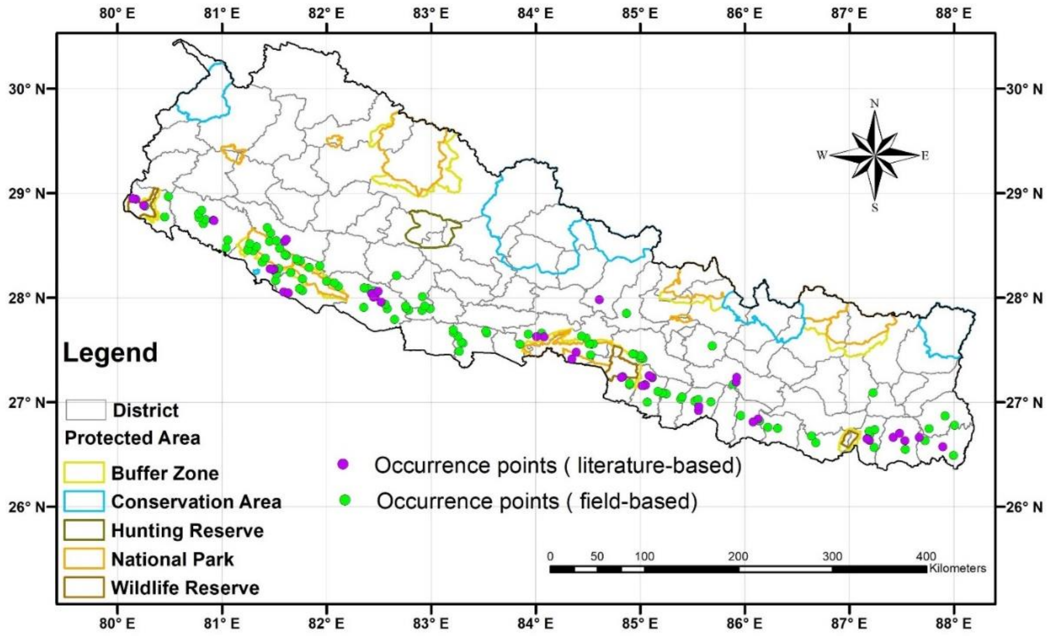

Figure 1. *Literature-based vs field-based occurrence points (R. serpentina distribution)*

Environmental variables data collection

A Digital Elevation Model (DEM) having a 30 m resolution was extracted from the website of the United States Geological Survey (https://earthexplorer.usgs.gov/). Slope and aspect were derived from the DEM using ArcGIS software (ESRI, 2017). Shapefiles of water sources were downloaded from the Geofabrik website (https://www.geofabrik.de/data/shapefiles.html) and converted to a distance raster file using ArcGIS (ESRI, 2017). The 19 bioclimatic variables (*Table 1*) were obtained from the Worldclim website (https://www.worldclim.org/).

Vegetation-related variables such as data related to forest cover were downloaded from the Global Forest Change (GFC) website (Hansen et al., 2013). The Enhanced Vegetation Index (EVI) was obtained from time-series data in 2018 and 2019, from images of Landsat 8. The Google Earth Engine was used to analyze this data. For anthropogenic variables, the shapefiles available on the Geofabrik website were used for the location of paths and roads (https://www.geofabrik.de/data/shapefiles.html). Settlement locations were obtained from the Department of Survey, Nepal. ArcGIS was used to create distance raster files of paths, roads, and settlements (ESRI, 2017). Land use and land cover (LULC) data were obtained from the International Centre for Integrated Mountain Development website (ICIMOD; http://www.icimod.org) (Uddin et al., 2015) and used in the model. All environmental variables were downloaded from freely available sources and preprocessed in ArcGIS (ESRI, 2017) to make an appropriate format (ASCII) and final spatial resolution (1 km).

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Table 1. *Environmental variables used for modeling*

Variables Name	Code	Database	Resolution
Annual Mean Temperature	BIO 1	WorldClim	30 arc s
Mean Diurnal Range [Mean of monthly (Max Temperature - Min Temperature)]	BIO 2	WorldClim	30 arc s
Isothermality (BIO 2/BIO 7) (*100)	BIO 3	WorldClim	30 arc s
Temperature Seasonality (Standard Deviation*100)	BIO 4	WorldClim	30 arc s
Max Temperature of Warmest Month	BIO 5	WorldClim	30 arc s
Min Temperature of Coldest Month	BIO 6	WorldClim	30 arc s
Temperature Annual Range (BIO 5-BIO 6)	BIO 7	WorldClim	30 arc s
Mean Temperature of Wettest Quarter	BIO 8	WorldClim	30 arc s
Mean Temperature of Driest Quarter	BIO 9	WorldClim	30 arc s
Mean Temperature of Warmest Quarter	BIO 10	WorldClim	30 arc s
Mean Temperature of Coldest Quarter	BIO 11	WorldClim	30 arc s
Annual Precipitation	BIO 12	WorldClim	30 arc s
Precipitation of Wettest Month	BIO 13	WorldClim	30 arc s
Precipitation of Driest Month	BIO 14	WorldClim	30 arc s
Precipitation Seasonality (Coefficient of Variation)	BIO15	WorldClim	30 arc s
Precipitation of Wettest Quarter	BIO 16	WorldClim	30 arc s
Precipitation of Driest Quarter	BIO 17	WorldClim	30 arc s
Precipitation of Warmest Quarter	BIO 18	WorldClim	30 arc s
Precipitation of Coldest Quarter	BIO 19	WorldClim	30 arc s
Distance to path	Dist_path	Geofabrik	30 arc s
Distance to road	Dist_road	Geofabrik	30 arc s
Distance to settlement	Dist_settlement	Department of Survey, Nepal	30 arc s
Distance to water	Dist_water	Geofabrik	30 arc s
Forest cover	Forest	Global Forest Change (GFC)	30 arc s
Livestock density	Liv_dens	Open data nepal https://opendatanepal.com/dataset/livestock-population	30 arc s
Land use land cover	Lulc	ICIMOD	30 arc s
EVI mean	EVI_mean	Images of Landsat 8 (1018 and 2019)	30 arc s
Population density	Pop_den	HUMDATA https://data.humdata.org/	30 arc s
Elevation	Elevation	USGS (https://earthexplorer.usgs.gov/	30 arc s
Aspect	Aspect	USGS (https://earthexplorer.usgs.gov/	30 arc s
Slope	Slope	USGS (https://earthexplorer.usgs.gov/	30 arc s

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Distribution modeling of species and accuracy assessment

Maximum Entropy (MaxEnt) software was used to predict the distribution of *R. serpentina* by using the species occurrence points and environmental variables (Elith et al., 2006; Phillips et al., 2006). This tool has been established as a widely used tool for predicting the distribution of species in Nepal (Aryal et al., 2016; Bista et al., 2018; Khim Bahadur et al., 2019; Panthi et al., 2019; Sharma et al., 2020). We selected location points while maintaining at least a 1 km distance between each other to lessen the spatial auto-correlation. Variation Inflation Factors (VIFs) of variables were calculated with the help of R software using packages of “VIF” and “ENMeval” (R Core Team, 2020). We used 11 variables out of 31 variables in the model as they had VIF 10. A total of 70% of the species occurrence points were allocated to the training dataset, and 30% were used as testing and validation datasets for all models. The models were evaluated by the two methods.

One method was threshold independent and another was threshold dependent. In the threshold independent method, the area under the receiver-operator curve (AUC) of models was reported (Wiley et al., 2003; Phillips et al., 2006). Higher AUC attributed to better model performance. The AUC <0.7 shows poor model performance, 0.7-0.9 shows moderately useful model performance, and >0.9 denotes excellent model performance (Pearce and Ferrier, 2000). Although AUC is a classical and widely used model evaluation parameter, it is criticized by some researchers (Lobo et al., 2008). Therefore, threshold-dependent accuracy assessment: True Skill Statistic (TSS) was also performed for the model evaluation (Merow et al., 2013). TSS was calculated for all model outputs (0-9 replications), and the final TSS was averaged of all 10 replications (Jiang et al., 2014; Panthi et al., 2019). Thresholds to maximize the sum of sensitivity and specificity are recommended threshold (Liu et al., 2013) so it was used to convert the habitat suitability map (raw output of MaxEnt) and to calculate the TSS. The suitable area was intersected by districts, physiographic zones, and protected areas to obtain n suitable area in each category.

Trade of R. serpentina

We interviewed farmers, traders, and exporters to know actual information about *R. serpentina* including marketing channels. Mapping of the value chain was also developed after consultation with various stakeholders who were directly or indirectly involved in *R. serpentina* production and marketing. During periods, we interviewed marketing companies and pharmaceutical industries as well. In order to gather information related to the trade of *R. serpentina*, we discussed it among the traders of Birtamod, Nepalgunj, and Bhairahawa in Nepal.

Rapid vulnerability assessment

The quantification of threats to high-valued medicinal plants was the major component of the study. After the checklist preparation, the next step is to find if the species are threatened or not, and if threatened, to what degree. To assess the threat status of medicinal plants, a method called rapid vulnerability assessment (RVA) was used to carry out for the prioritized species of MPs. This method was developed by Cunningham (1996) and used in Bwindi National Park, Rwanda. In Nepal, it has been used by Tripathi and Schmitt (2001), Rokaya (2002), and Ghimire and Aumeeruddy-Thomas (2005). The

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modified RVA method was used by Wagner et al., 2008 for the endangerment assessment of medicinal plants from Muktinath Valley and Kali Gandaki in Central Nepal.

A total of eight vulnerability criteria were used for each species. For each of the eight predictors of vulnerability a score ranging from 1 to 4 (1 being low and 4 being high vulnerability) was assigned for each species. The assignment of values to a particular category was done based on vulnerability. Local users were interviewed to obtain information on plant parts used (criteria 1) and data were validated against secondary literature. The species whose roots and rhizomes are utilized are more vulnerable as the entire plant has to be destroyed to collect these parts. Therefore, this criterion was given the highest value. Life forms (criteria 2) were assessed from secondary literature (*Table 2*).

Table 2. *Criteria for vulnerability*

SN	Criteria	Categories	Score
1	Plant parts used	Rhizome/root/whole plant	4
		Bark, stem	3
		Inflorescence, flower, fruit, seed	2
		Leaves	1
2	Life forms	Long-lived perennial	4
		Short-lived perennial	3
		Multi-year	2
		Annual	1
3	Habitat	Gravel/soil, rocky/stony slopes	4
		Moist, marshy, permanent snow melting zone	3
		Forests, shrubberies, agricultural land	2
		Grassland/pastureland/ meadow	1
4	Geographical distribution	Nepal endemic	4
		Himalaya endemic	3
		Himalaya surrounding countries	2
		Cosmopolitan	1
5	Habitat specificity and local population size	Few places sparse	4
		Few places thin	3
		Many places thick or thin	2
		Everywhere thick or thin	1
6	The amount traded per year	>5000 kg	4
		3000–5000 kg	3
		1000–3000 kg	2
		<1000 kg	1
7	Official conservation/ threat designation	Status in 3 categories or more	4
		Status in 2 categories	3
		Status in 1 category	2
		Not assigned	1
8	User group	Local people, local exchange, trade	4
		Local people, trade	3
		Local people, local exchange	2
		Local people	1

The threat categorization was calculated by submission of all scores, and found whether it falls on threat category I >25 or threat category II= 20-24 or threat category III = 15-19 or threat category IV= 5-14 (Shrestha et al. 2012)

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Results

Suitable area

R. serpentina was found mostly in the Terai region of Nepal. This species was recorded below the altitude of 1000 m above mean sea level (MSL). Our results indicate that the total suitable habitat for *R. serpentina* in Nepal is 35362.9 km^2 (24% of the total area of Nepal). Of the total suitable area, 5230.92 km^2 (15%) of the area was inside the protected area system. After running the model using various bio-climate variables, we found that most of Nepal's Terai region, which is rich in organic matter and has moderately light areas, is the best suited for *R. serpentina (Figure 2)*.

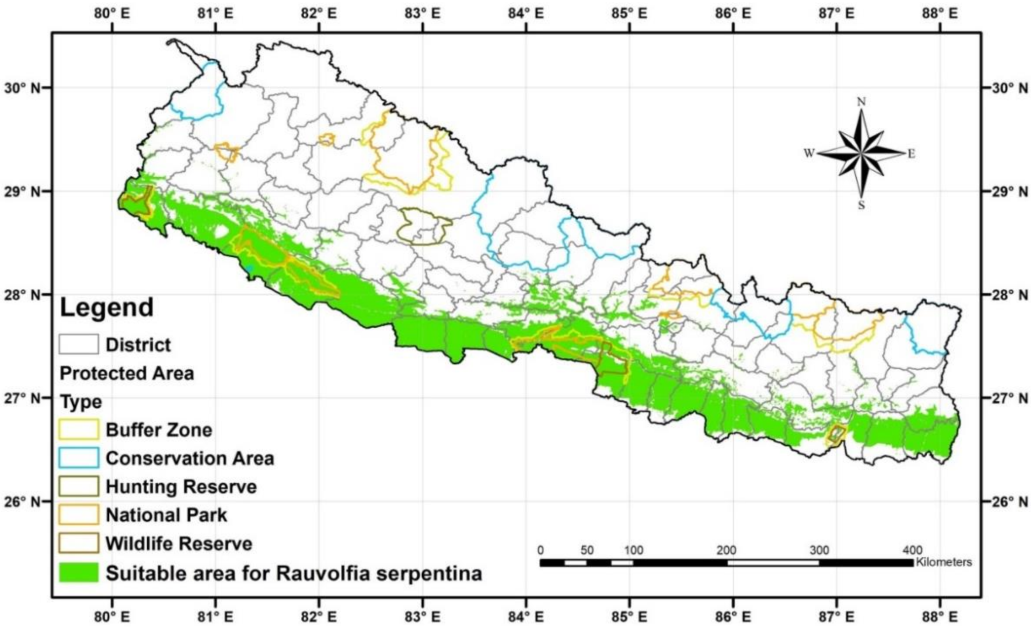

Figure 2. *Potential distribution of R. serpentina in Nepal*

R. serpentina was also found in Nepal`s Terai-protected areas. The largest suitable habitat was encompassed by Chitwan NP followed by Bardiya NP, Chitwan BZ, Banke NP, and Parsa NP respectively (*Table 3*).

Table 3. *Suitable area of R. serpentina inside the protected areas of Nepal*

Protected area	Area (km^2)
Chitwan National Park	1024.04
Bardia National Park	853.11
Chitwan Buffer Zone	746.48
Banke National Park	543.85
Parsa National Park	486.03
Suklaphanta NP	379.77
Banke Buffer Zone	332.16
Bardia Buffer Zone	322.58
Parsa Buffer Zone	232.46
Suklaphanta Buffer Zone	221.04
KoshiTappu Wildlife Reserve	57.97
Blackbuck Conservation Area	17.08
Koshi Tappu Buffer Zone	14.35

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Our results signified that the Siwalik region encompassed the largest suitable habitat followed by the Terai region and Middle Mountain (*Table 4*). There was negligible suitable habitat in the high mountain region whereas there was no suitable habitat in the high Himalayas.

Table 4. *Suitable area according to physiographic zones*

Physiographic zones	Area (km^2)	% of total suitable habitat
High Himalayas	0	0
Middle Mountain	4680.482	13
High Mountain	2.807872	Nearly 0
Terai	12117.27	34
Siwalik	18562.35	52

The largest suitable habitat was found in Dang district followed by Kailali, Bardiya, Chitwan and Banke districts (*Table 5*). The majority of highly suitable districts were located in the western lowlands of Nepal. The area of each district can be used in developing district management plans to promote better cultivation of *R. serpentina*.

Table 5. *District-wise suitable area of R. Serpentina of Nepal*

DISTRICT	Area (km^2)	DISTRICT	Area (km^2)	DISTRICT	Area (km^2)
Dang	2709.156	Ilam	677.3458	Achham	78.63442
Kailali	2384.749	Nawalprasi_W	668.4326	Kathmandu	64.55407
Bardiya	1958.691	Udaypur	664.2788	Lalitpur	49.11986
Chitwan	1877.286	Sunsari	574.4083	Kavrepalanchwok	39.80049
Banke	1785.853	Saptari	468.1827	Dailekh	38.63534
Kapilvastu	1638.257	Sindhuli	434.8705	Lamjung	31.16167
Kanchanpur	1420.385	Salyan	391.5912	Panchthar	29.8498
Jhapa	1397.005	Argakhanchi	377.264	Okhaldhunga	26.90925
Rupandehi	1296.858	Pyuthan	352.302	Rolpa	20.10264
Makawanpur	1228.985	Palpa	341.1329	Tehrathum	19.71495
Parsa	1118.942	Dhading	323.0677	Ramechhap	18.61814
Bara	1093.897	Dadeldhura	278.4774	Bhaktapur	15.09913
Sarlahi	1085.969	Dhankuta	133.4077	Darchula	14.34687
Surkhet	1073.563	Nuwakot	126.1766	Sindhupalchwok	13.40551
Nawalparasi_E	1047.422	Gorkha	125.41	Gulmi	8.361645
Morang	1004.849	Syangja	112.1164	Jajarkot	6.904668
Dhanusha	946.5698	Doti	100.6135	Sankhuwashabha	5.464334
Siraha	869.9782	Khotang	100.0432	Baglung	3.37078
Mahottari	833.2634	Baitadi	98.46362	Parbat	3.209012
Rautahat	792.7156	Kaski	95.93013	Rukum_W	2.368127
Tanahun	775.0084	Bhojpur	82.96026	Rasuwa	1.032801

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Importance of variables

Elevation, BIO 1, Bio 15, and forest had the highest percentage contribution for the generation of the model (*Table 6*). The jackknife regularized training gain for each variable and their contribution without and with only a particular variable is given in the figure below representing the environmental variable with the highest gain when used in isolation, and the variable that decreases the gain the most when it is absent (*Figure 3*).

Table 6. *Percentage contribution and permutation importance of variables*

Variables	Percent contribution	Permutation importance
elevation	42.1	3.6
bio1	16.9	33.2
bio15	10.3	17.5
forest	7.1	6.8
bio8	7.1	8
popden	6.2	13.1
bio10	5.3	2.9
lulc	2.9	11.2
dist_road	0.9	1.8
bio5	0.7	1.5
dist_settle	0.5	0.3

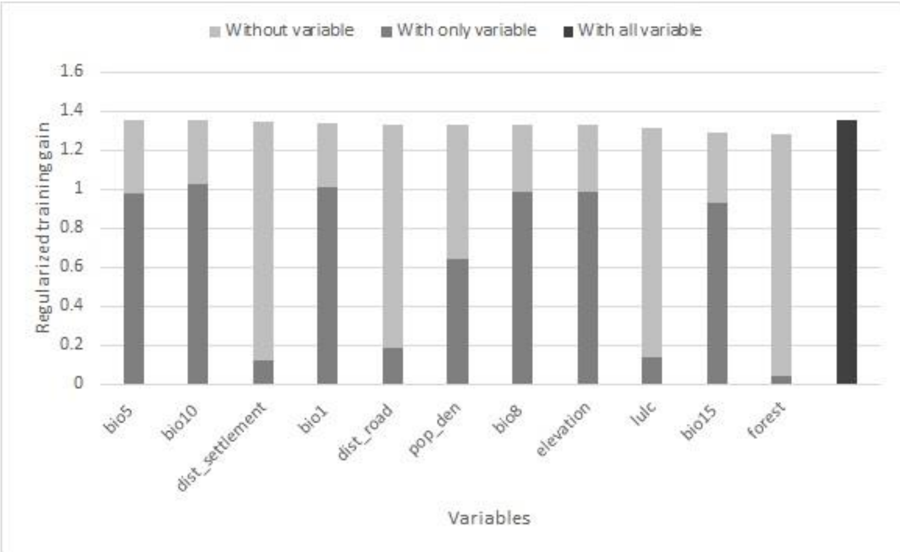

Figure 3. *Regularized training gain for each variable*

Among the variable used in the model, Elevation, Mean annual temperature, precipitation seasonality, and Forest type are the most influencing variables for *R. serpentina* distribution.

Response curves for the four most important variables are given below (*Figure 4*).

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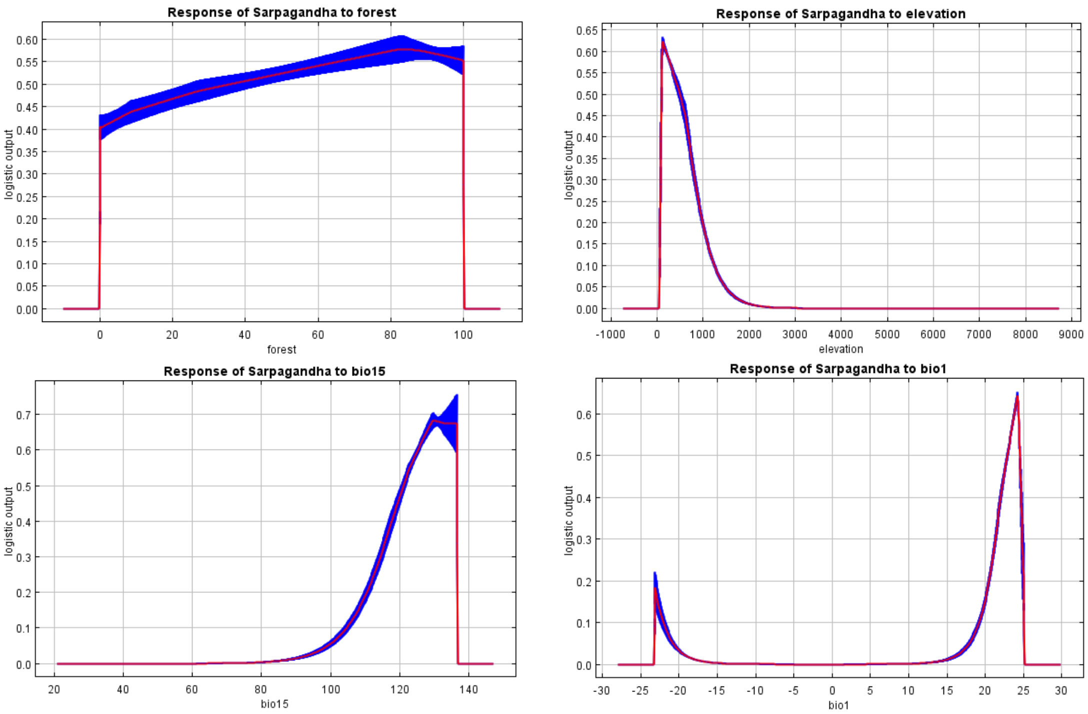

Figure 4. *Response curves for the four most important variables*

The above figures illustrate that the habitat suitability of *R. serpentina* increases with an increase in forest cover percentage. Elevation highly influences habitat distribution. With increasing altitude after 900 m, it starts to fall off or has low suitability. Likewise, precipitation seasonality has positive effects on habitat suitability. *R. serpentina* requires an annual mean temperature of 20–25 degrees Celsius. The chances of suitability become low in cold temperatures.

Model accuracy

The accuracy of the model was quite good with an average AUC of 0.92±0.004 and an average TSS of 0.62±0.03 (*Table 7*).

Table. 7. *Model accuracy of R. serpentina*

Replications	AUC	TSS
1	0.9196	0.57
2	0.9203	0.61
3	0.9158	0.66
4	0.924	0.65
5	0.9221	0.63
6	0.9262	0.63
7	0.9222	0.65
8	0.9229	0.67
9	0.9147	0.61
10	0.9146	0.58
Average	0.9202	0.62
Standard deviation	0.004037	0.0334

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Price and trade status

It is obvious that the price of *R. serpentina* is increasing in the national and international markets. While comparing the price of *R. serpentina* in six years, its price is consistently increasing. The demand in the international markets is very high, but production is very low in Nepal`s Terai. The *Figure 5* illustrates the increasing trends in *R. serpentina`s* price in Nepal (JABAN, 2020).

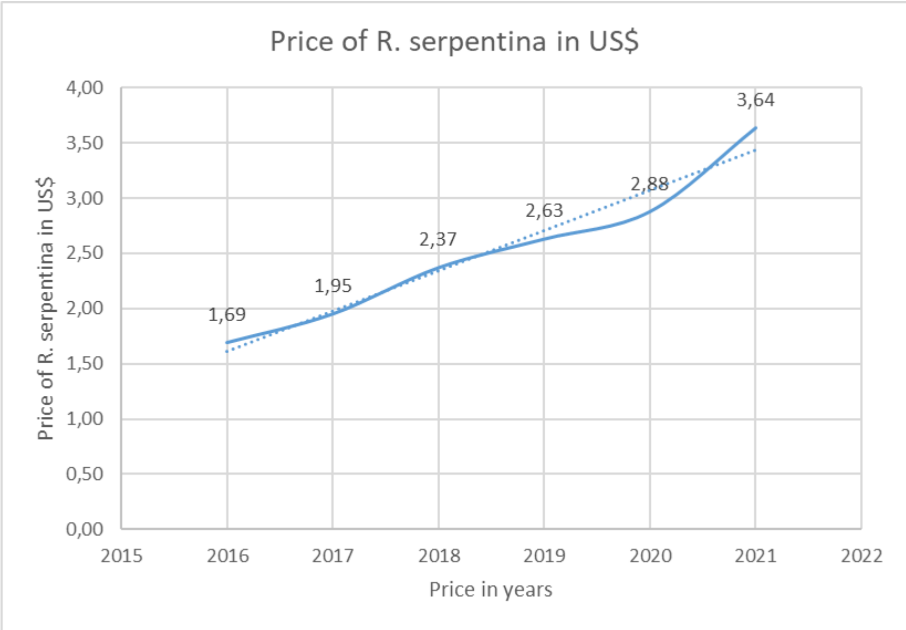

Figure 5. *Price of per kg R. serpentina in Nepal*

Trade channel of R. serpentina

According to the FAO survey in 1993, 400–500 t of roots are gathered each year, mostly in India, Thailand, Bangladesh, and Sri Lanka (IQBAL, 1993). Although the species was mostly supplied from Uttaranchal, large quantities were also imported from Bhutan, Nepal, and Pakistan, according to traders in the Delhi marketplaces in the late 1990s (Traffic India, 1998). In Nepal, the market price for *R. serpentina* is US$ 12 per kilogram. Only 500 kilograms of dried roots were harvested from Nepal's Terai region and utilized as raw materials for the Ayurvedic industries in Nepal. Exporting raw materials without processing is illegal in Nepal (DOF, 2021). In our research, we found that India was the major country buying *R. serpentina*. However, the USA, China, and European countries are the major buyers of *R. serpentina*. The trading channel of *R. Serpentina* has been sketched below (*Figure 6*).

In Nepal, *R. serpentina* is harvested either from cultivation or wild in community forests or government-managed forests. According to the records of the Jadibuti Association of Nepal, 500 tons were collected in 2020 from the community and government-managed forests. Now, such quantities are decreasing because people heavily harvested due to high demands in India. Traders sell *R.serpentina* to district-level traders or regional traders or directly to medicinal plant processing centers. After the first level of processing, it is only eligible for exporting in India and other parts of the world.

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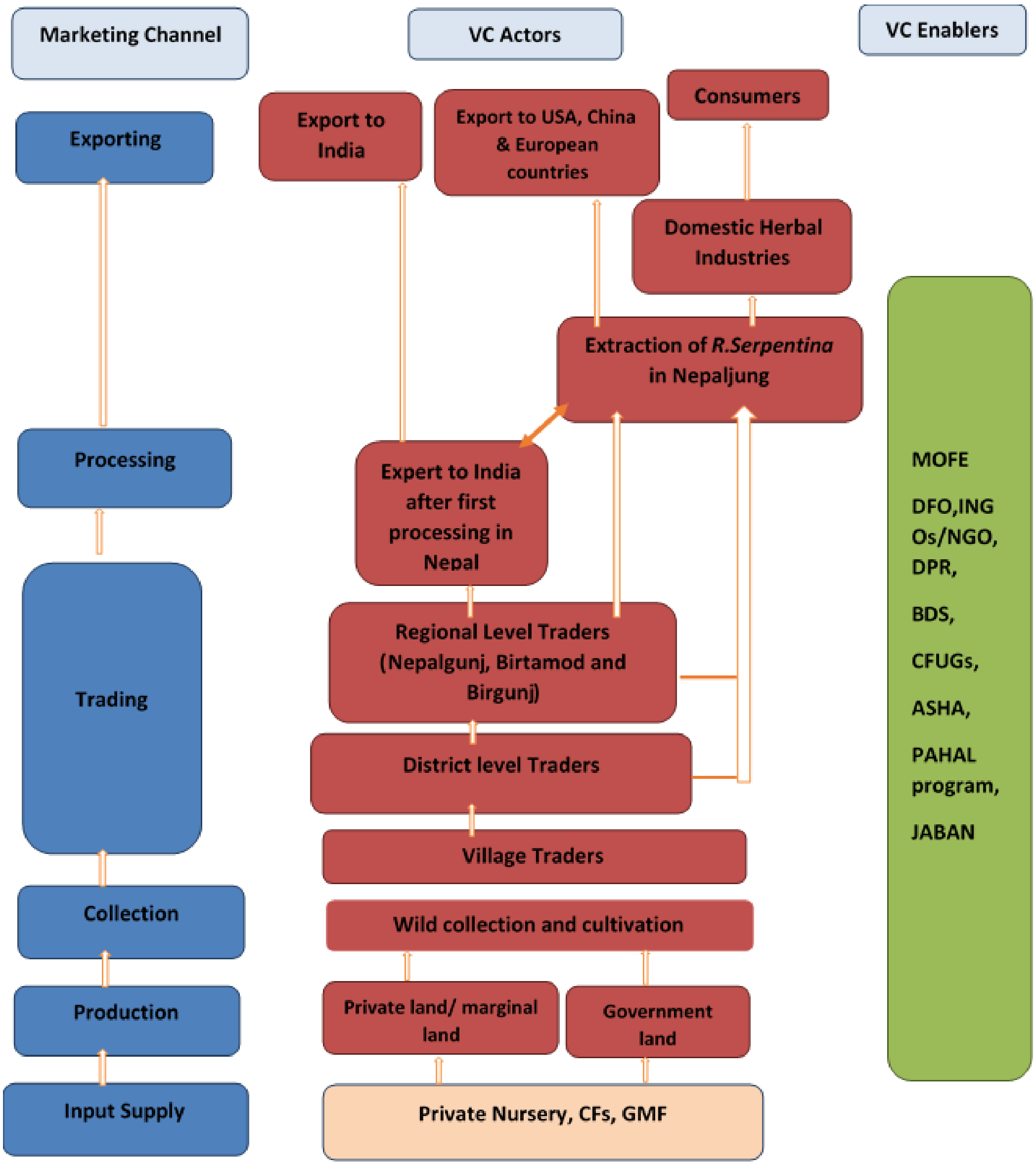

Where, VC= Value China, MOFE= Ministry of Forest and Environment, DFO= District Forest Office, INGOs=International Non-Governmental Organization, DPR= Department of Plant Resource, CFUG = Community Forestry User Group, JBAN=Jadibuti Association of Nepal, CFs= Community Forests, BDS= Business Development Services, GFM= Government Managed Forest

Figure 6. *Trade channel of R. serpentina*

Authorized institutions

R. serpentina can be obtained from wild or natural habitats or cultivation. The species is restricted to export without processing. Therefore, this species has been encouraged at least the first level of processing within the country. According to the focus group discussion among the traders, we concluded that India, Germany, France, and China are the major consumers of *R. serpentina*. The process of international exporting of *R.serpentina* has been given below (*Figure 7*).

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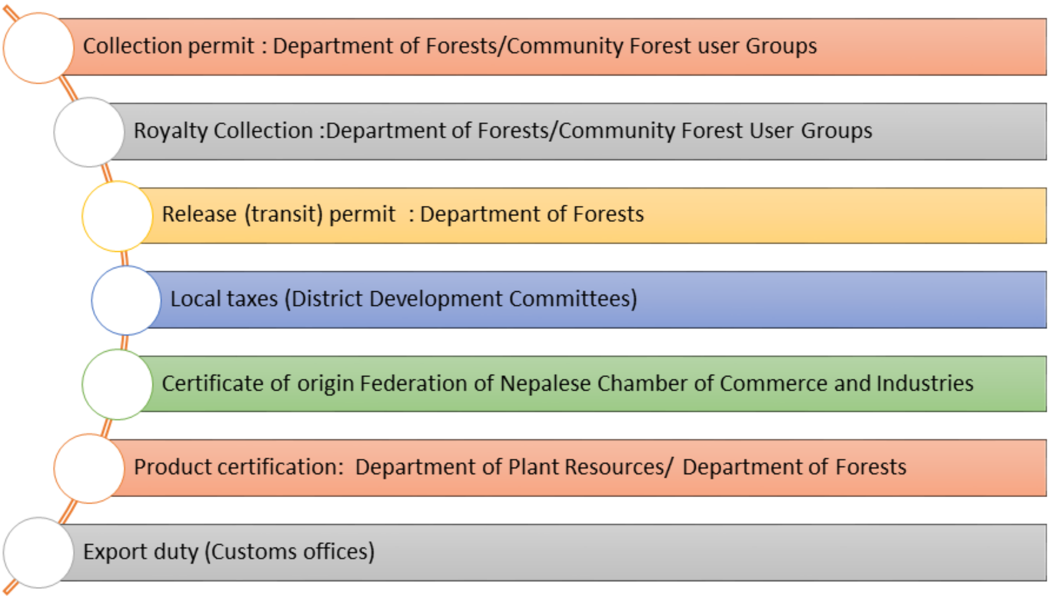

Figure 7. *Authorized institutions while exporting R. serpentina (JABAN, 2020)*

Threats assessment

The threats of *R. serpentina* were calculated using different criteria and indicators using the method developed by Shrestha et al. (2012). We summarized the average score in core Terai, Siwalik, and Mid-hills. The *R. serpentina* is heavily harvested in the core Terai region of Nepal compared to Siwalik and Mid-hills. Therefore, we received the highest score of 25 in core Terai. Heavily harvesting was the indicator of high threats because commercial harvesting was carried out only in the core Terai region of Nepal. According to the score obtained, we concluded that core Terai is the highest threat followed by Siwalik and Mid-hills of Nepal.

Table 8. *Analysis of threat of R. serpentina*

SN	Criteria	Average score in core Terai	Average score in Siwalik	Average score in Mid-hills	Average Score
1	Plant parts used	4	4	4	4.00
2	Life forms	3	3	3	3.00
3	Habitat	1	2	2	1.67
4	Geographical	2	2	2	2.00
5	Habitat specificity	3	4	4	3.67
6	The amount traded per year	4	1	1	2.00
7	Official conservation/	4	4	4	4.00
8	User group	4	3	3	3.33
	Total score	25	23	23	23.67
	Category	I	II	II	II

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Discussion

Rauwolfia serpentina is used especially for the treatment of hypertension and psychotic disorders (Ali et al., 2022). *R. serpentina* was predominantly found in Nepal's Terai region. We observed this species below the height of 1000 meters above MSL. According to our findings, Nepal's total suitable habitat for *R. serpentina* is 35362.9 km^2 (twenty-four percent of the total area of Nepal), whereas 5,230.92 km^2 (15%) of the total suitable area was included within the protected areas. According to the National Parks and Wildlife Conservation Act (1973), the cultivation of *R. serpentina* should not be possible in protected areas. However, domestication and cultivation might be encouraged in the buffer zones of protected areas in Nepal. After running the model with various 31 environmental variables, we concluded that the core Terai region of Nepal, rich in organic matter and moderate light, was ideal for *R. serpentina* cultivation.

The rainy season when many medicinal plants begin to bloom is the best chance to sight many medicinal plants (Kunwar et al., 2022). Therefore, a field study was carried out from June to December, 2021 in order to capture the possible species' location points. *Fig. 1* compared literature-based and field-based occurrence points. Field-based species location points have been seen as more extended compared to literature-based. According to the predicted final map of the suitable habitat for *R. serpentina* (*Fig.* 2), most of the districts are in the Terai region of Nepal. According to Kunwar (2019), *R. serpentina* is found at altitudes below 900 m (MSL). MaXent is very robust, requiring presence only, and has an easy-to-use interface, allowing to maintain higher accuracy predictions under various constraints (Dunk et al., 2019; Kaky et al., 2020). Selecting previously determined variables and gradually removing the least contributing variables are two new methods of variable selection (Zeng et al., 2016). Altogether 31 environmental variables were used to run the model (*Table 1*). Elevation, bio 1, bio 15, forest, and bio 8 were the most contributed variable in the model, contributed 42.1%, 16.9%, 10.3%, 7.1%, and 7.1%, respectively (refer to *Table 7*, *Fig. 3*, and *Fig. 4*). *Table 7* shows the accuracy of the model. We replicated the model 10 times and achieved an average AUC of 0.9202 with a TSS value of 0.62, giving the model excellent predictive accuracy. While talking about the suitable area according to physiological zone, the Siwalik zone was the most favorable (*Table 4*), accounting for 52% of the total suitable area. This is because grasslands and organic matter deposition affect the overall distribution of the species. Among the districts, Dang, Kailali, and Bardiya were the top three districts in terms of the potential distribution of *R.serpentina* (*Table 5*). Most of the GPS points were recorded from the mid-western and far-western regions of Nepal. The Western region of Nepal was more abundance of *R. serpentina* compared to eastern Nepal. In *Table 6*, Elevation, BIO 1, BIO 15, and forest had the highest percentage contribution for the generation of the model. *R. serpentina* requires an annual mean temperature of 20–25 degrees Celsius (*Fig. 4*). The Siwalik area was the most suitable for growing *R. serpentina* while analyzing all variables. The reason why the price of *R. serpentina* is increasing each year due to fewer collections and no more meaningful strategies for growing *R. serpentina* on private land (*Fig. 5*).

After interviewing key traders among 30 persons in Damak, Nepaljung, Birjung and Bhairahawa, we prepared the value chain map for *R. serpentina* (*Fig. 6*). Both community forests and private cultivators supplied *R. serpentina* to regional level traders. After processing, Nepal exports in India (80%) and European countries (10%), and remaining 10% for domestic consumption. According to a demand and supply assessment conducted by the Centre for Research Planning and Action (CERPA) in New Delhi in 2004, 500 MT

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of *R. Sarpagandha* was demanded in the Indian subcontinent in 2004/05 (Poudel, 2007). According to Tiwari et al. (2004), a total of 30,225 kg of *R. serpentina* was demanded by governmental and non-governmental Ayurvedic companies/trading houses in the Kathmandu valley. That study documented the herbs consumed by Ayurvedic practitioners as well as local consumption inside the valley. Annual NTFP exports from Nepal to India (Source: Indian Trade Centre, Tanakpur, India, 2003) show that 15 MT of total *R. serpentina* were exchanged at a buying rate of 190-200 rupees per kilogram. (Poudel, 2007). The invention of reserpine-based pharmaceuticals in the 1950s increased demand for *R. serpentina*, which was mostly supplied by India (Sheldon et al., 1997), which had a monopoly on crude drug supply for the world market at one point (Government of India, 1989). In the early 1980s, the global demand for *R. serpentina* was projected to be 100–150 t per year. Domestic demand in India alone was expected to be over 400 t in 2000/2001, indicating a huge increase (ANON, 2001-2002). Prior to *R. serpentina's* inclusion in CITES Appendix II, the majority of pharmaceuticals used in the United States and Europe came from India, Pakistan, Sri Lanka, Myanmar, and Thailand (Government of India, 1989). Only 500 kg of dried roots of *R. serpentina* was cultivated from the private lands and nearly nil from the government-managed forest. Cultivation of such valuable species is needed for consumption in domestic industries and international markets (DOF, 2021). Exporting *R. serpentina* to international markets was not very easy (according to field experience) and involved seven major steps from collection permit to customs (*Fig. 7*).

R. serpentina has been classified as an endangered species by the IUCN as critically endangered by the CAMP workshop (Bhattarai et al., 2002). It is listed in Appendix II of the Convention on International Trade in Endangered Species. Its export as a crude drug has been prohibited by the Nepalese government. *R. serpentina* is endangered in natural habitat, however, we can conserve this valuable species by cultivating in farmer`s land (Kumari et al., 2021). According to Shrestha et al. (2012), eight vulnerable criteria are the best idea to judge each species whether it is under threat or not. For each of the eight predictors of vulnerability, a score between 1 and 4 was assigned to each criterion (1 indicating low vulnerability and 4 indicating high vulnerability) (*Table 2*). R. serpentina is summarized as Category II, requiring conservation in its natural habitat (*Table 8*). With clearance from the Department of Forests, it can be exported in processed form (GoN, 2005b). It is one of Nepal's most important medicinal herbs for research and commercial production (GoN, 2005a). The average threat level of R. *serpentina* is medium in Nepal. However, the core Terai region is highly threatened because of the fact that wild harvesting of *R. serpentina* was carried out within these areas of Nepal. After the first level of processing, Nepal exports 85% of *R. serpentina* to India and consumes 15% for local Ayurveda companies. In 2021, Nepal exported 127.5 tons of *R. serpentina* to India, and 22.5 tons to domestic pharmaceutical companies (DPP, 2022). According to the results, we can say that Terai and Siwalik Hills are the most probable regions for cultivation and management. Government of Nepal (GON) has already started cultivation practices of high-value medicinal plants for increasing incomes, and ex-situ conservation of endangered species (Shrestha et al., 2020). Domestication and cultivation of this species are urgently needed for future courses of action. However, policy and strategies should be in favor of small farmers who grow such a valuable and endangered species.

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Conclusion

R. serpentina is collected in Nepal either through cultivation or from the wild in the community or government-managed forests. Traders offer *R. serpentina* to the district or regional-level traders as well as to medicinal plant processing centers directly. According to different bio-climatic variables and occurrence points, the Terai region of Nepal is the most suitable habitat for *R. serpentina*. From the study, we concluded that 24% of the total area of Nepal is suitable habitat for *Rauvolfia serpentina*. The government of Nepal (GoN) has also given priority to this species for cultivation and promotion. People in the Terai region of Nepal would be benefitted through *R. serpentina* cultivation and could promote sustainable livelihoods through *R. serpentina* farming and trading. Out of all the suitable areas, 5230.92 km^2 (15%) are suitable in protected areas. Out of 77 districts in Nepal, 63 districts are suitable for *R. serpentina* cultivation, trade, and promotion. However, 17 districts of Nepal, which fall under the Siwalik and Terai regions, are the most suitable for *R. Serpentina*. Dang is the most suitable district in Nepal, followed by Kailali, Bardiya, Chitwan, and Banke. The Western lowlands are the most suitable habitat for *R. serpentina*. The accuracy of the model was excellent, with an average AUC of 0.92±0.004 and an average TSS of 0.62±0.03. It is only eligible for export in India and other parts of the globe after the first step of processing. Siwalik region of Nepal is the most suitable habitat, followed by the Terai and Middle Mountains. It is negligibly suitable in the high mountains and not suitable in the high Himalayas. Campaigns for cultivation practices are needed in the most suitable areas, which are imperative actions for the future commercial cultivation and conservation perspective.

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APPENDIX

Table 1. *List of occurrence points*

S.N.	Latitude	Longitude	Altitude
1	28.28107	81.54231	170
2	28.45632	81.24868	161
3	28.4601	81.24233	172
4	28.45098	81.29973	168
5	28.16387	81.51342	147
6	28.7736	80.45322	201
7	28.55286	81.05685	154
8	28.51731	81.26756	194
9	28.47792	81.03992	146
10	28.37917	81.41347	217
11	28.01032	82.91656	832
12	27.85077	84.86882	823
13	27.356896°	85.712219°	992
14	27.03172	85.38987	102
15	27.17102	85.89042	533
16	26.69473	87.19753	105
17	26.72399	87.19118	107
18	26.87026	87.91758	625
19	26.63159	87.72649	126
20	26.54968	87.53621	89
21	26.56826	87.23945	88
22	26.61398	86.67934	112
23	26.675756°	86.316190°	90
24	26.87292	85.96273	126
25	27.00003	85.06846	93
26	27.45236	84.52726	662
27	27.55612	83.84884	402
28	27.56551	83.30432	106
29	27.79172	82.65289	330
30	27.90781	82.35573	287
31	28.15782	82.00235	841
32	28.24125	81.65847	173
33	28.71036	80.82069	180
34	28.21354	82.66955	997
35	28.30616	81.93541	514
36	28.97082	80.488	560
37	28.87543	80.2643	206
38	28.83811	80.80529	851
39	28.80702	80.77615	338
40	28.76637	80.781	204
41	28.74879	80.84484	286
42	28.66995	81.43495	382
43	28.6191	81.46697	368

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S.N.	Latitude	Longitude	Altitude
44	28.54065	81.45552	426
45	28.54505	81.52134	631
46	28.47265	81.55112	653
47	28.41275	81.60505	300
48	28.40675	81.61524	310
49	28.37281	81.71405	527
50	28.35819	81.72604	424
51	28.35331	81.74984	520
52	28.28997	81.83309	446
53	28.18032	81.76929	180
54	28.06851	81.77084	159
55	28.14257	82.07398	625
56	28.11066	82.1137	748
57	28.09347	82.35839	655
58	28.08867	82.39944	664
59	28.06772	82.45659	690
60	27.93757	82.5631	451
61	27.89735	82.58039	863
62	27.92039	82.75579	727
63	27.90116	82.75995	485
64	27.88185	82.78643	472
65	27.88041	82.91329	584
66	27.92136	82.94048	543
67	27.8968	82.99099	971
68	27.69442	83.21375	172
69	27.66755	83.21187	147
70	27.634	83.25771	118
71	27.57571	83.28956	106
72	27.48875	83.26978	98
73	27.68197	83.52388	204
74	27.66285	83.53253	151
75	27.65299	83.93169	360
76	27.66168	84.05785	218
77	27.63377	84.43953	198
78	27.61683	84.48023	201
79	27.56019	84.51444	190
80	27.55605	84.53763	196
81	27.55942	84.55307	199
82	27.18018	84.89707	132
83	27.16671	84.89917	116
84	27.15773	85.03381	151
85	27.23591	85.11508	212
86	27.10397	85.17179	127
87	27.08786	85.21277	122
88	27.08287	85.25228	118
89	27.05196	85.40077	107

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S.N.	Latitude	Longitude	Altitude
90	27.00995	85.52432	111
91	27.02707	85.55389	121
92	27.00607	85.67827	152
93	26.82197	86.14053	97
94	26.75966	86.22139	94
95	26.7506	86.31642	119
96	26.67877	86.63937	204
97	26.73876	87.24424	159
98	26.74941	87.76304	322
99	26.4913	87.99758	101
100	26.78186	88.00728	499
101	27.09215	87.22719	645
102	28.08776	81.74009	143
103	28.23053	81.52469	159
104	28.34079	81.38684	161
105	28.48839	81.33171	193
106	27.42135	85.01785	433
107	27.41875	85.02578	450
108	27.42117	85.02308	468
109	27.42203	84.99691	420
110	27.43216	85.01572	520
111	27.44642	85.00401	664
112	27.4615	84.94764	486
113	27.46388	84.93005	442
114	28.455	81.24778	158
115	27.95972	81.79056	145
116	27.97222	81.79417	147
117	28.69418	80.98716	189

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