PREDICTING HABITAT SUITABILITY AND THREATS ASSESSMENT OF HIMALAYAN YEW (*TAXUS WALLICHIANA* ZUCC.) IN NEPAL

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Abstract. *Taxus wallichiana* Zucc. is globally recognized as a powerful anti-cancer tree that grows naturally in the Himalayas and parts of Southeast Asia. Needles and bark containing taxol are used to treat different types of cancer. Therefore, this study aimed to analyze the habitat suitability and potential threats of *Taxus wallichiana* Zucc. in Nepal. The suitable area for *Taxus wallichiana* Zucc. is about 11% (15781.59 km^2) of the total area of Nepal, mainly in the mountains and Himalayan regions of Nepal. While using the Maximum Entropy (MaxEnt) software to predict the potential distribution, elevation, isothermality (BIO-3), Normalized Vegetation Index (NDVI), and land use/land cover were the most influential among 31 variables. The accuracy of the model was excellent with an average Area under the receiver-operator curve (AUC) of 0.96±0.002 and an average True Skills Statistics (TSS) of 0.66±0.038. While analyzing the top four key variables, altitude, isothermality, land use/land cover and NDVI mean were highly influenced for the model. Therefore, we might promote *Taxus wallichiana* with elevation range (1000-4200 m), isothermality (32%-52.5%), land use/land cover (forest type), and NDVI (0.3-0.8). *Taxus wallichiana* can be cultivated in 56 mountains and Himalayan districts of Nepal with an elevation from 1000 m to 4200 m above Mean Sea Level (MSL). The high-value medicinal plant itself became the cause of threats to natural habitats. The collection of bark and leaves for sale, over-grazing, heavy use in construction, and lack of awareness were the top causes of threats of *Taxus wallichiana* in Nepal. The Government of Nepal should start cultivation in 56 potential districts of Nepal so that it can be conserved locally and served to the world as raw material for research and production of anti-cancer drugs.
Keywords: *Taxus wallichiana, distribution, cultivation, vulnerability assessment, endangered species*

Introduction

Taxus wallichiana, locally known as Lauth Salla, also known as Himalayan Yew, is one of the cancer-curing plants, found growing in Nepal, Afghanistan, Bhutan, China, India, Indonesia, Malaysia, Myanmar, Pakistan, Philippines, and Vietnam at the altitude range of 1500-3500 m asl (Subba, 2018). It is primarily found at an altitude of 2600 m above MSL (Thomos and Farjon, 2011). It is an endangered gymnosperm, with high economic and medicinal importance for its cancer-curing properties (Wang et al., 2008) around the world and in Hindu Kush Himalaya (Hao et al., 2015) and is mainly used for furniture, incense,

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and fodder (Thomas and Farjon, 2011). The most powerful and effective anticancer drugs derived from *Taxus wallichiana* (Yang et al., 2017) contain taxol which has huge demand in the international market (Miao et al., 2015). It is very difficult to identify yew species due to similar leaf characteristics (Moller et al., 2007). *Taxus wallichiana* contains large amounts of phenols and terpenoids, which are beneficial for chronic diseases of the spine (Sinha, 2020). It is also used as fodder, fencing, timber for local use as well as for sale in Tibet, as a housing construction material, and as a medicine against cancer and jaundice (Gajurel et al., 2015).

According to an examination of herbarium specimens and literature, *T. wallichiana* was first collected in Nepal by Nathaniel Wallich in 1822. In his Tentaman Florae Nepalensis, "Sheopore (meant Shivapuri)," near Kathmandu, he documented its existence in Nepal. Baglung, Bajhang, Darchula, Dhankuta, Dolakha, Dolpa, Doti, Gorkha, Humla, Jajarkot, Jumla, Kaski, Kathmandu, Lamjung, Manang, Mustang, Myagdi, Parbat, Rasuwa, Sankhuwasabha, Solukhumbu, and Taplejung are the 22 representative districts enlisted as *T. wallichiana* habitats, according to the Ethnobotanical Society of Nepal (1997). It grows in conjunction with *Quercus semecarpifolia* Sm*.*, *Abies spectabilis* D. Don*.*, *Picea smithiana* Craib*.*, *Cedrus deodara* G. Don*.*, *Tsuga dumosa* D. Don*.*, *Pinus wallichiana* A. B. Jacks*.*, and *Rhododendron campanulatum* D. Don*.* in Western, Central, and Eastern sub-alpine and temperate zones of Nepal between 1800 and 3000 meters (Joshi, 2009).

Himalayan forests are the most depleted in the world (Shaheen et al., 2011), and major causes of deterioration were tree harvesting, overgrazing, and nomadic activities (Ahmad et al., 1990; Ahmad et al., 2012). Unfortunately, there is very little awareness of its protection among the people. Also, no harvesting guidelines exist for its sustainable harvesting and collection (Rokaya et al., 2017). This species has been listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix II and banned for export under the Forest Act (2018) of the Government of Nepal. However, with the recommendation of the Department of Plant Resources or the Herbs Production and Processing Company Limited and the pre-approval of the Department of Forests, its processed material can be exported. Their leaves are collected with the permission of DFO (Government royalty: US$ 0.1893 per kg) (Forest Regulation, 2075). This species is one of the 33 highly prioritized medicinal and aromatic plants for economic development, cultivation, and research by the Government of Nepal (Bhatt et al., 2017). Although Taxus tree species are growing naturally in 39 Mountain districts of Nepal, very limited research works has been carried out to prescribe the harvestable amount of leafy biomass of Taxus (Yadav, 2014).

Species distribution modeling includes ecological niches, habitat suitability, and potential ranges which are used to identify species distributions and species patterns (Elith and Graham, 2009; Soberon and Nakamura, 2009). Species occurrence is related to environmental factors (Qiao et al., 2015). Habitat fitness models can be viewed as operational applications of ecological niche modeling based on a set of environmental variables that predict the presence or absence of species (Hirzel and Le Lay, 2008). Environmental factors (temperature, water, soil, humidity, etc.) have a significant influence on species distribution. For decades, researchers have focused on plant-environment interactions and their impacts on plant growth (Elith and Leathwick, 2009; Scheper et al., 2013; Fortunel et al., 2014). People from different socio-economic backgrounds and cultural settings including indigenous communities (Sherpa, Tamang, Rai, and Gurung communities) plant *Taxus wallichiana* for commercial purposes due to medicinal as well as marketing potential (Gajurel et al., 2015). Some people in the Himalayas harvest *Taxus*

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wallichiana to cure the problem of bones, joints, stomach aches, and breathing difficulties (Poudel et al., 2013).

T. wallichiana population in Nepal was assessed as Endangered in 2001 by a CAMP workshop held in Nepal, due to a decline in population size and decrease in range caused by exploitation (Anon, 2001). In the mid-1990s, exploitation of wood shingles in rural areas was considered a major problem in Nepal (Amatya, 2005). Nepal's CITES Management Authority stated that the species was threatened in the wild in Nepal after consulting with members of the CITES Scientific Authority (Sharma, 2006). Artificial propagation, particularly stem cuttings, is favored in Nepal since natural regeneration is sluggish and difficult (Amatya, 2005). *T. wallichiana* is most commonly gathered and commercialized in Nepal under the name of Lauth Salla, Talispatra and Thingre Salla. Leaves and twigs are the most common portions gathered, but the bark is occasionally taken as well (Mulliken et al., 2008). The preferred season for harvesting is summer, and harvesting is carried out in 15 districts (Amatya, 2005). Harvesters can harvest up to 72 kg of fresh leaves per day (equivalent to 36 kg of dry leaves) (Paudel, 1998). Harvesting of *Taxus wallichiana* is not practiced sustainably and requires urgent national assessment, reportedly declining due to heavy debarking and logging in the Himalayas (Purohit et al., 2001). Due to high economic demand and over-harvesting, *Taxus wallichiana* ranked in the endangered category and is at risk of extinction (Paul, 2013). Although the leafy biomass of *Taxus* is highly valued for an amorphous substance called taxol, an important medicine for the treatment of several forms of cancer; very sparse information is known about its resource status, distribution, and sustainable management practices (Yadav, 2014).

Cultivation practices are the best appropriate method for conserving endangered species (Gaire et al., 2022). For conserving *Taxus wallichiana*, alternative method of producing paclitaxel using endophytic fungi will be another option (Jian et al., 2017). Paclitaxel is a very important molecule, used in hospitals for treating cancer patients (Lasala et al., 2006). Endophytic fungi effectively produce paclitaxel from *Taxus wallichiana* (Nicholas et al., 2004). In this paper, we analyzed the potential distribution suitability of *Taxus wallichiana* in Nepal. Moreover, we also highlighted the risk and threats of *Taxus wallichina* for which immediate action is needed in the future. The Nepalese government has also prioritized this species for cultivation promotion. The most suitable areas might be used for cultivation practices, whereas this species is conserved inside the protected areas for non-commercial purposes. The conservation practices would automatically help to protect this species from threats of extinction. Therefore, the objectives of the study were: (1) to predict the habitat suitability of *Taxus wallichina* in Nepal, and 2) to evaluate the threats assessment using Rapid Vulnerability Method (RVM) and existing conservation scenario indicators.

Materials and methods

Study area

Taxus wallichiana is an evergreen species that grows between 900 m and 3700 m above sea level (ICIMOD, 2021). Therefore, the study was carried out in Nepal with altitudes ranging from 700 m to 4000 m (*Figure 1*). The study covers different physiographic zones of Nepal such as Mid-hills, Mountains, and high Himalayas. The scope of *Taxus wallichiana* is between Mid-hills to the High Himalayan region of Nepal. We collected the species location information of *Taxus wallichiana* in the 27 potential districts of Nepal.

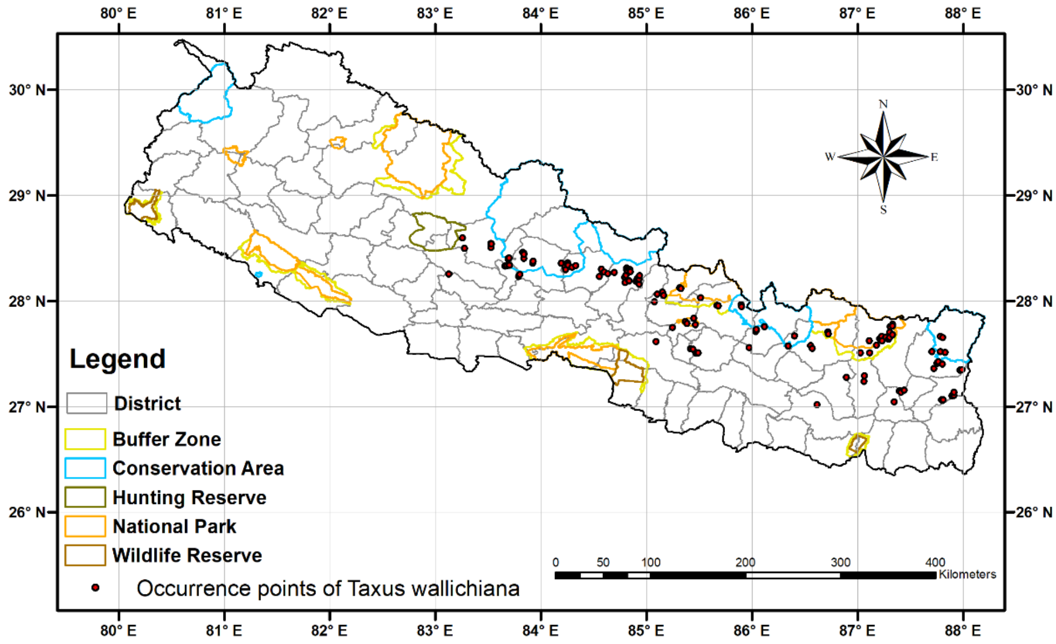

***Figure 1.** Overview of species location points of Taxus wallichiana*

Collection of occurrence points

For *Taxus wallichiana*, we collected the 130 occurrence points from 23 districts of Nepal (*Figure 2*). *Taxus wallichiana* is an evergreen species that grows between 900 m and 3700 m above sea level (ICIMOD, 2021). Therefore, the study was carried out in Nepal with altitudes ranging from 700 m to 4000 m. The study covers different physiographic zones of Nepal such as Mid-hills, Mountains, and high Himalayas. The scope of *Taxus wallichiana* is between Mid-hills to the High Himalayan region of Nepal. The survey was conducted in Nepal from October 2021 to December 2022. The Gramin GPSMAP 65 was used to record the species location points in order to minimize errors as possible. We collected the species location information of *Taxus wallichiana* in the 27 potential districts of Nepal.

We collected the 130 occurrence points from 23 districts of Nepal. *Table 1* lists the number of occurrence points of *Taxus wallichiana* by district.

Environmental variables data collection

Digital Elevation Model (DEM) with a resolution of 30 m was extracted from the US Geological Survey website (https://earthexplorer.usgs.gov/). using ArcGIS software, slope and aspect were extracted from the DEM (ESRI, 2017). We used the Geofabrik website (https://www.geofabrik.de/data/shapefiles.html) for downloading shapefiles of water sources, and converted to distance raster files (ESRI, 2017). The 19 bioclimatic variables (*Table 2*) were downloaded 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 Normalized Different Vegetative Index (NDVI) was obtained from the following website: https://neo.gsfc.nasa.gov using time-series data of 2018 and 2021, from images of the Landsat 8 which was analyzed using the Google Earth Engine.

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Figure 2. *Sample of occurrence points of Taxus wallichiana*

Table 1. *Recording the occurrence points of Taxus wallichiana in Nepal*

S.N.	District	Number of occurrence points	Place
1	Rasuwa	7	Thulo Pakho,Tatopani
2	Kathmandu	5	Shivapuri, Nagarjun, Bagdwara, Borlabhanjyang
3	Sindhupalchwok	3	Helambu, Thampakot
4	Dolakha	3	Suspa,Babare Ban
5	Solukhumbu	4	Lukla, Chuchure
6	Sankhuwasabha	18	Chayasekharka,Kharka Gaun,Tasigaun,Dandakharka,Hatiya, Sisiwakhola,Sapsu Dhap
7	Bhojpur	3	Halaucha, Boya
8	Dhankuta	3	Tindure, Tute, Guransedanda
9	Tehathum	2	Basantapur, Arun Valley
10	Ilam	3	Chhintapu
11	Panchthar	3	Sidin
12	Taplejung	11	Kalikhola, way to pathibhara tample, Lepchung, Olangchunggola, Tapethok
13	Makawanpur	2	Risheshwor Temple area, Chitlang, Near Chandragiri hills
14	Baglung	1	Heel
15	Myagdi	4	Chimkhola
16	Kaski	13	Ghorepani, Gandhuk, Panchase area
17	Parbat	3	Lespark, Upper Kyang
18	Lamjung	12	Bhujung, Dudhpokhari, Dhodeni, Lipu hill, Pasgaun, Ghanpokhara
19	Gorkha	18	Uhiya and Kashigaun nearby ares
20	Rasuwa	5	Dandagaun, Salme
21	Kavre	3	Dhunkharka, Bhumidanda, Maningkhel
22	Ramechhap	2	Khola Kharka
23	Nuwakot	2	Shersang

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Table 2. *Environmental variables used for modeling*

Variables Name	Code
Annual Mean Temperature	BIO 1
Mean Diurnal Range [Mean of monthly (Max Temperature - Min Temperature)]	BIO 2
Isothermality (BIO 2/BIO 7) (*100)	BIO 3
Temperature Seasonality (Standard Deviation*100)	BIO 4
Max Temperature of Warmest Month	BIO 5
Min Temperature of Coldest Month	BIO 6
Temperature Annual Range (BIO 5-BIO 6)	BIO 7
Mean Temperature of Wettest Quarter	BIO 8
Mean Temperature of Driest Quarter	BIO 9
Mean Temperature of Warmest Quarter	BIO 10
Mean Temperature of Coldest Quarter	BIO 11
Annual Precipitation	BIO 12
Precipitation of Wettest Month	BIO 13
Precipitation of Driest Month	BIO 14
Precipitation Seasonality (Coefficient of Variation)	BIO15
Precipitation of Wettest Quarter	BIO 16
Precipitation of Driest Quarter	BIO 17
Precipitation of Warmest Quarter	BIO 18
Precipitation of Coldest Quarter	BIO 19
Distance to path	Dist_path
Distance to road	Dist_road
Distance to settlement	Dist_settlement
Distance to water	Dist_water
Forest	Forest
Livestock density	Liv_dens
Land use land cover	Lulc
NDVI mean	Ndvi_mean
Population density	Pop_den
Elevation	Elevation
Aspect	Aspect
Slope	Slope

For anthropogenic variables, shapefiles were used to locate the paths and roads available on the Geofabrik website (https://www.geofabrik.de/data/shapefiles.html). Settlement locations were received 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 into the model. All environmental variables were downloaded using the freely available sources, and pre-processed in ArcGIS (ESRI, 2017) to make the appropriate format (ASCII) at 1 km final spatial resolution.

Distribution modeling of species and accuracy assessment

Maximum Entropy (MaxEnt) software was used to predict species distribution based on species origin and environment variables (Elith et al., 2006; Phillips et al., 2006). This tool has been widely used to predict species distributions of both plants and animals (Aryal et al., 2016; Bista et al., 2018; Khim Bahadur et al., 2019; Sharma et al., 2020). MaxEnt has been widely used to predict the cultivation suitable of valuable plants as well

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(Zhang et al., 2018). MaxEnt has become a common species distribution model for minimizing errors and easing prediction (Fourcade et al., 2014). We chose points that were at least 1 km apart to reduce spatial autocorrelation. In order to avoid multicollinearity between any two variables, the variance inflation factor (VIF) function was performed using the 'DAAG' package in R statistical software (R Core Team, 2020). We used 16 out of the 31 variables in the model because they had VIF<10. A total of 70% of the species occurrence points were allocated for the training dataset, and 30% were used as a testing /validation dataset for all models. The models were evaluated by 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, namely 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). Thresholds to maximize the sum of sensitivity and specificity was 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 a suitable area for each category.

Threats assessment

The study was carried out from October 2021 to December 2022 in ten major districts of Nepal, namely: Lamjung, Gorkha, Kathmandu, Rasuwa, Kaski, Parbat, Myagdi, Dhankuta, Sankhuwashabha, and Taplejung. However, we collected the occurrence points from 23 districts of Nepal (Mountain and Himalayan districts of Nepal). An average of 5 discussions were carried out among the local people within each district. We discussed with key informants in many ways in order to capture the information related to *Taxus walichiana* and its existing and possible threats. Both semi-structured and unstructured questionnaires were prepared to capture people's perceptions and opinions on the causes of threats to this species. Altogether, a total of 300 interviews were organized and conducted (30 in each of the selected districts) (*Table 3*). Field observation was also conducted using a checklist on the morphological features and habitats of *Taxus wallichiana*.

Table 3. *District Number of key informants interviewer*

District Name	Informal discussions	Key informant interviews
Lamjung	6	30
Gorkha	4	30
Lamjung	4	30
Rasuwa	4	30
Kaski	6	30
Parbat	4	30
Myagdi	5	30
Dhankuta	6	30
Sankhuwashabha	3	30
Taplejung	2	30

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Threat assessment was also evaluated using the Rapid Vulnerability Assessment (RVA) using Cunningham (1996). This method was used and modified by Wagner et al. (2008). Plant parts used, life forms, habitat, geological distribution, habitat specificity/population size, the amount traded per year, official conservation/threat designation, and user group management were the major indicators for analyzing the threat categories. Each category has been sub-divided into 4 different indicators and given a weighted value from 1 to 4 (Wagner et al., 2008). Threat categorization was calculated by adding all scores), and categorized as First (I)> 25, Second (II) = 20-24, third (III) = 15-19, and four (IV)= 5-14 (Shrestha and Shrestha, 2012).

Results

Habitat suitability of Taxus wallichiana

Our results show that the total suitable habitat for *Taxus wallichiana* in Nepal is 15781.59 km^2 (11% of the total area of Nepal). Out of the total suitable area, 4350.59 km^2 (28%) of area was inside the protected area system (*Figure 3*). The majority (72%) were suitable outside the protected areas of Nepal. The largest suitable habitat was encompassed by Annapurna CA followed by Api Nampa CA, Dhorpatan HR, Kangchenjunga CA, Khaptad NP and Langtang BZ.

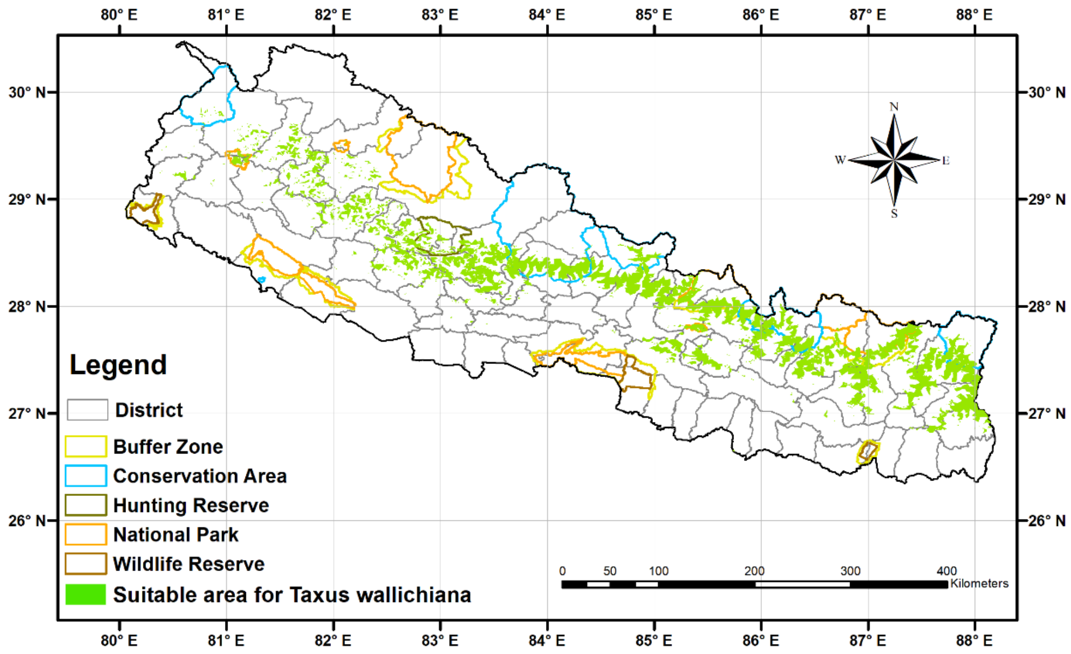

Figure 3. *Habitat suitability map of Taxus wallichiana in Nepal*

Suitability in the protected area

Regarding the in-situ conservation of *Taxus wallichiana*, the protected areas are the best place to conserve this endangered species in the long-term because there is a restriction on collection and trade of this species within protected areas. A total of 5 Conservation Areas (CAs), 6 National Parks (NPs), 1 Hunting Reserve (HR), and 4 buffer zones (BZs) are suitable habitats for *Taxus wallichiana*. The habitat distribution of

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Taxus wallichiana inside the protected area of Nepal is a good indication of long-term survival of the species. However, the professional farmers have already started growing *Taxus wallichiana* on their own farms by registering private forestry. The details of the suitable area are shown in *Table 4*.

Table 4. *Suitable area inside PAs*

Protected area of Nepal	Area (km^2)
Annapurna CA	966.8353
Api Nampa CA	840.6631
Dhorpatan HR	423.6449
Kangchenjung CA	379.2623
Khaptad NP	370.6404
Langtang Buffer Zone	328.084
Langtang NP	299.8126
Manaslu CA	239.2147
Rara NP	235.7009
Sagarmatha Buffer Zone	104.411
Sagarmatha NP	81.43039
Shivapuri NP	38.70227
Makalu Barun BZ	31.58117
Gaurishankar CA	5.473762
Makalu Barun NP	5.018171
Sagarmatha Buffer Zone	0.062143
Sagarmatha NP	0.062143
Total	4350.599

Suitable area according to physiographic zones

Our results signified that high mountain encompassed the largest suitable habitat followed by middle Mountain range and high Himalayas (*Table 5*). There was negligible suitable habitat in the Terai and Siwalik regions of Nepal.

Table 5. *Total suitable area according to physiographic zones*

Details	Area (km^2)	Altiudinal range
High Mountain	11501.26	2700-4000m
Middle Mountain	3662.349	1500-2700m
High Himalayas	610.9259	>4000m
Terai	2.283559	60-300m
Siwalik	0.517625	700-1500m

Suitable area (District-wise)

Of the 77 districts of Nepal,the high majority (56 districts) were suitable for *Taxus wallichiana*. Taplejung, Sankhuwashabha, Sindhupalchwok , Baglung, Gorkha, Myagdi, Solukhumbu, Dolakha,Kaski, and Lamjung were the top ten districts of Nepal where we might initiate the *Taxus wallichiana* for commercial cultivation. Local farmers and cultivators are definitely beneficial when analyzing the distribution by districts. A district-wise analysis will assist foresters or growers in designing district-level management plans for cultivating and promoting of the valuable *Taxus wallichiana*. District-wise suitable area of *Taxus wallichiana* has been presented in *Table 6*.

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Table 6. *District-wise habitat suitability area of Taxus wallichiana*

District	Area (km^2)	District	Area (km^2)	District	Area (km^2)
Taplejung	1253.42	Bajura	311.189	Salyan	23.6332
Sangkhuwashabha	1037.5	Nuwakot	297.218	Udaypur	14.3467
Sindhupalchwok	927.813	Makawanpur	242.257	Syanjha	13.9452
Baglung	863.33	Okhaldhunga	237.889	Sindhuli	12.8486
Gorkha	816.712	Rukum_W	230.754	Argakhanchi	12.5211
Myagdi	764.978	Kavrepalanchwok	202.97	Bhaktapur	11.1741
Solukhumbu	725.193	Jumla	154.791	Manang	9.924
Dolakha	711.675	Terhathum	154.169	Mugu	5.51597
Kaski	612.3	Bajhang	136.022	Baitadi	4.74479
Lamjung	596.777	Parbat	129.689	Chitwan	3.85791
Jajarkot	492.619	Pyuthan	119.382	Mahottari	2.09066
Rukum_E	481.354	Lalitpur	103.324	Surkhet	1.67986
Panchthar	455.134	Kathmandu	97.1084	Palpa	1.5438
Rasuwa	425.105	Gulmi	87.8572	Tanahun	1.51986
Rolpa	412.985	Dailekh	86.701	-	-
Ilam	391.107	Doti	72.1038	-	-
Dhading	381.768	Dhankuta	71.428	-	-
Kalikot	372.694	Dadeldhura	57.7892	-	-
Ramechhap	351.017	Achham	47.3608	-	-
Bhojpur	350.194	Darchula	32.0984	-	-
Khotang	335.425	Morang	31.0389	-	-

Importance of variables

Elevation, isothermality (BIO-3), NDVI mean, and land use/land cover had the highest influence on model generation. The jackknife regularized training gain for variables and their contributions without and with only a particular variable is given in the figure below (*Figure 4*).

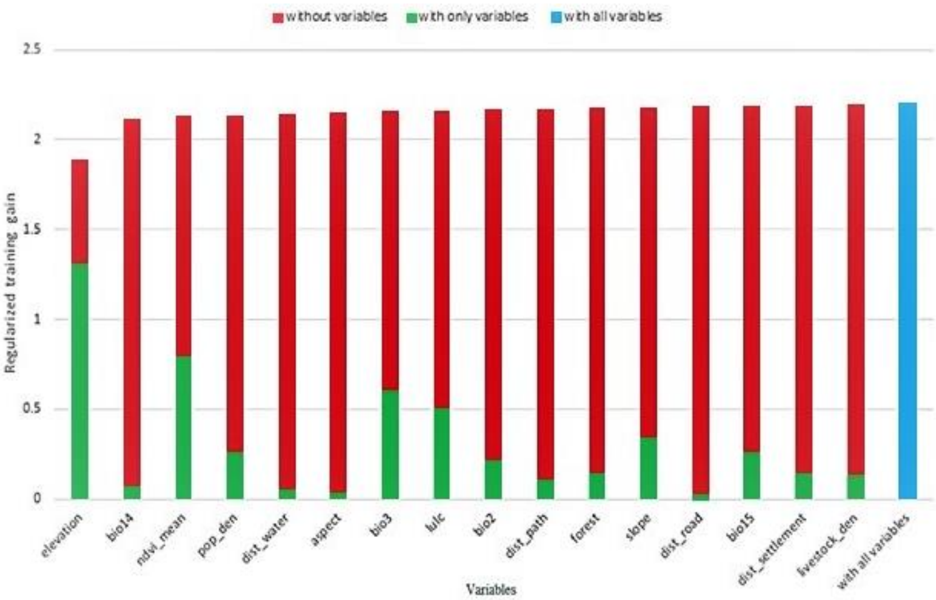

Figure 4. *The jackknife regularized training gain of top 16 important variables*

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Response curves for four most important variables are given below (*Figure 5*).

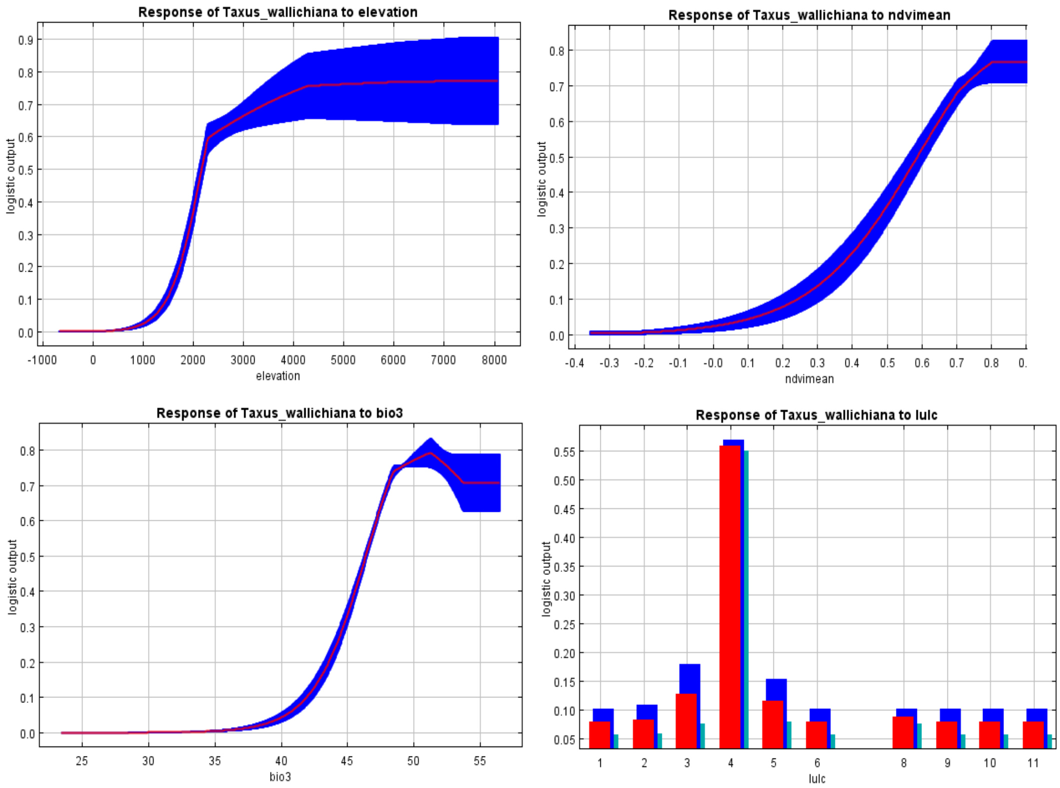

Figure 5. *Response curves of four important variables*

Altitude is the main indicator for most medicinal plants in Nepal (Gaire et al., 2021). Elevation, Bio-3, NDVI and land use/land cover were analyzed deeply. The suitability of *Taxus wallichiana* started only at an altitude of 2000 m. At 4200 m, the maximum probability of the species is 0.75. The probability of suitability increased from 1000 m to 4200 m. After 4200 m, the probability increased, but it was not effective due to an increase in standard deviation. The result signified that the elevation from 2000 to 4200 m was a good logistic output. In the case of NDVI, the value of NDVI increased to 0.8. Values above 0.6 indicate the temperate regions of Nepal. Therefore, this species is more suitable for the Mountain and Himalayan regions of Nepal. Isothermality of *Taxus wallichiana* received 52.5% with a probability of 0.79. The isothermality increases with increasing percentage (>35%) up to 52.5%. This species prefers cooler diurnal temperature, which was about half of Nepal`s mean annual temperature. For the land use/land cover, the highest probability (0.55) was received from forest types. We mostly recorded this species in the temperature regions of Nepal. Therefore, the nature of the response curve was found similar when we visited sites to collect the occurrences of *Taxus wallichiana*.

Model accuracy

The accuracy of the model was quite good with average AUC of 0.96±0.002 and an average TSS of 0.66±0.038. The AUC value for the training data was 0.9674 which indicated a high degree of accuracy for the MaxEnt predictions (*Table 7*).

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Table 7. *Analyzing the accuracy of the model*

Models	AUC	TSS
1	0.9668	0.643
2	0.9655	0.716
3	0.971	0.648
4	0.9667	0.721
5	0.9658	0.663
6	0.9647	0.598
7	0.9657	0.679
8	0.9703	0.701
9	0.9703	0.654
10	0.967	0.633
Average	0.9674±0.002	0.6656±0.038

Threats assessment

There was not only a single cause for the threat of *Taxus wallichiana*. There were many reasons why this species was in danger of extinction. In order to find out the actual causes, we organized the key informants' interview to identify the genuine cause of the threats. According to the questionnaire asked the key informants for judging the threat status of *Taxus wallichiana*, the following rank was received (*Tables 8*, *9*).

Table 8. *Possible treats of Taxus wallichina*

Threats	Rank	Reasons/Uses
Collection of bark and leaves for selling purposes to traders	I	In the Himalayan region of Nepal, NTFP traders usually buy *Taxus wallichiana* leaves and bark at an average price of US$ 2.30-3.069 /kg (dry weight). Due to poor livelihood, local people earn income to cover their living expenses.
Over-grazing	II	Due to lack of protection or fences, cattle graze freely in the jungles of the mountains and Himalayas of Nepal. *Taxus wallichiana* has not yet regenerated well due to overgrazing.
Construction	III	The wood of *Taxus wallichiana* is very durable and can be used as strong building materials such as beams, doors, and windows. The demand for *Taxus wallichiana* wood is very high in most of the temperate regions of Nepal.
Lack of awareness	IV	The innocent rural local people were unaware of the importance of the species. Even they do not know on why conserve this species.
Over harvesting	V	Peeled bark and lopped branches sold in the market or consumed in the family as medicinal value
Slow growing	VI	This species has a slow-growing nature with a long seed dormancy period (1.5 to 2 years).
Firewood collection	VII	Due to its flammable nature, locals prefer to cook and keep warm in the cold season.
Decoration purpose	VIII	Because the wood has a beautiful red color, local people also use it as a decoration
Medicinal use	IX	Local people make Yogurt from Taxus`s Theki. They believe that consuming Yogurt of Taxus wood might reduce the chances of cancer. Nowadays, people use leaves as green tea. It has lots of health benefits (fever, cough, pneumonia etc.)
Others	X	Used as bridge and also as wooden structure for soil and erosion control in hilly areas of Nepal.

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Table 9. *Threats category in Mid-hills, high-mountains and High-Himalayas of Nepal*

SN	Criteria	Average Score in Core Mid-hills	Average score in Mountains	Average score in High-Himalayas	Average Score	Remarks
1	Plant parts used	1	1	3	1.67	Only leaves are used in mid-hills and high mountains whereas bark and steam are used in the Himalayan regions of Nepal.
2	Life forms	4	4	4	4.00	Long-live (Tree category)
3	Habitat	2	2	1	1.67	Along with other temperate forests of Nepal besides the Himalayan regions
4	Geographical	3	3	3	3.00	This species is the Himalayan endemic
5	Habitat specificity	3	3	4	3.33	Not dense forest
6	The amount traded per year	1	4	3	2.67	Heavy harvesting from the high mountain regions of Nepal rather than mid-hillls and high Himalayas
7	Official conservation/	4	4	4	4.00	Government of Nepal, IUCN and CITES has enlisted this species as endangered species
8	User group	3	3	4	3.33	Local people, exchange and trade
	Total score	21	24	26	23.67	
	Category	II	II	I	II	

Majority of people highlighted that collection of bark and leaves for selling purpose to traders were the major threats of *Taxus wallichiana*. Likewise, over-grazing, construction and lack of awareness were also the top issues for the threats of *Taxus wallichiana*. However, all the issues were equally important to the long-term survival of *Taxus wallichiana* in future courses (*Figure 6*).

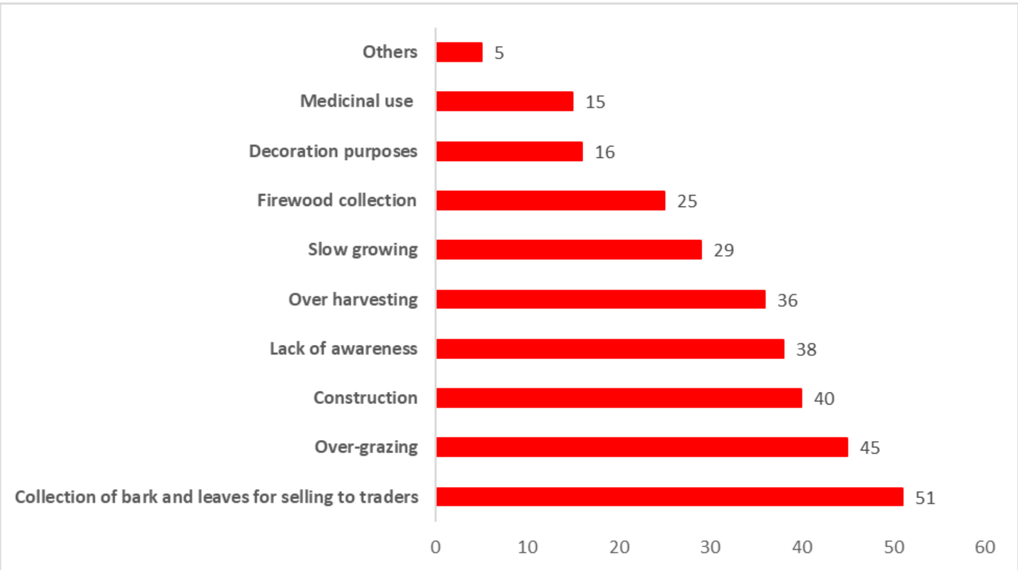

Figure 6. *Respondents' opinions on threats of Taxus wallichiana*

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The majority (51) of the respondents answered that the unbalanced collection of bark and leaves for selling to traders was the main cause of the threat. The over-grazing (45) ranked as second followed by construction (40), lack of awareness (38), over harvesting (36), slow growing (29), firewood collection (25), decoration purpose (16), medicinal use (15) and others (5). The livelihoods of the rural people have also been linked with the harvesting of *Taxus wallichiana*.

While analyzing the threats using Shrestha and Shrestha (2012), we found that the Himalayan region is threat category (I) followed by the High Himalayan (II) and Mid-hills of Nepal (*Table 9*).

Discussion

Three species of yew (*Taxus wallichiana*, *Taxus mairei* and *Taxus contorta*) are distributed in 42 districts and are among the most traded and expensive species in Nepal (Poudel et al., 2012; Kunwar et al., 2020). The occurrence points of *Taxus wallichina* was received using park officials who have worked for many years in Nepal`s protected areas. Regarding species locations outside the national park, our team was dedicated to collect the location points. *Table 1* represented the occurrence points where we collected the *Taxus wallichiana* locations points.

While discussing the potential distribution of *Taxus wallichiana* in Nepal, the eastern part of Nepal was more suitable than the far-western region of Nepal (*Fig. 2*). The eastern part of Nepal is the prime habitat of *Taxus wallichina* rather than the western part of Nepal (Gagurel et al., 2014). The mountainous and Himalayan regions of Nepal were the most suitable areas for *Taxus wallichiana*. *Fig. 2* illustrated that the majority (72%) falls outside the protected areas of Nepal. Therefore, it would be a highly possible scope for domestication and cultivation in the mountain and Himalayan regions of Nepal. The protected area of Nepal is also a habitat for *Taxus wallichiana*. According to our visit, the majority of occurrence points were received from the eastern part of Nepal. The eastern parts of Nepal were more suitable than the western and far-western regions of Nepal.

According to *Table 5*, we can conclude that the high mountains followed by middle mountains and the high Himalayas were the most suitable areas for the cultivation of *Taxus wallichiana*. Therefore, for commercial cultivation, the mountains and midhills were the most suitable in all aspects. According to *Table 6*, the largest suitable habitat was found in Taplejung district followed by Sangkhuwashabha**,** Sindhupalchwok, Baglung, Gorkha, Myagdi, Solukhumbu, Dolakha, Kaski, Lamjung, Jajarkot, Rukum_E, Panchthar**,** Rasuwa, Rolpa, Ilam, Dhading, Kalikot, Ramechhap, Bhojpur, Khotang, Bajura, Nuwakot, Makawanpur, Okhaldhunga, Rukum_W, Kavrepalanchwok, Jumla, Terhathum, Bajhang, Parbat, Pyuthan, Lalitpur, Kathmandu, Gulmi, Dailekh, Doti, Dhankuta, Dadeldhura, Achham, Darchula, Morang, Salyan, Udaypur, Syanjha, Sindhuli, Argakhanchi, Bhaktapur, Manang, Mugu, Baitadi, Chitwan Mahottari, Surkhet, Palpa and Tanahun. *Taxus wallichiana* is a drought-sensitive species, preferring to grow under abundant rainfall and cool temperate montane and submontane climate regimes (Thomas and Lianming, 2013). The majority of the highly suitable districts are located in the highlands (Mid-hills, High Mountain and High Himalayas) of Nepal.

An area of 4350.59 km^2 was evaluated as suitable within the protected area of Nepal (refer to *Table 5*: Protected area-wise suitable areas of Nepal). The Annapurna conservation was the highest suitable area (966.8353 km^2) while Sagarmatha NP (0.062143) was slightly suitable. The regularized training gains of 31 different variables

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were used to test whether these variables have influence for modeling. Out of the 31 variables, only 16 were found to have influence on the habitat suitability of *Taxus wallichiana* or to predict the potential distribution. Among the 16 main variables, only 4 variables (Elevation, BIO_3, Mean NDVI, and land use/cover) played an important role in predicting the habitat distribution of *Taxus wallichiana* (*Fig. 4*). The altitudinal range varies according to the species of Yew (Gajurel, 2016). Elevation got the maximum generalized training gain in isolation. *Taxus wallichiana*, an evergreen tree is found at altitudes between 1800 and 3300 m above MSL (Juyal et al., 2014). Therefore, *Taxus wallichina* might not be possible to grow in lowlands of Nepal. NDVI above 0.6 represents temperate regions (Hoek et al., 2019). Therefore, this species suits the temperate range rather than Nepal's tropical and sub-tropical regions (*Fig. 5*).

The projected shrink in climatic niche of *Taxus wallichiana* by 28% (RCP 4.5) and 31% (RCP 8.5) indicates the vulnerability of the endangered species to climate change impacts (Rathore et al., 2019). *Fig. 6* illustrates that the Majority (51) of respondents responded that the haphazard collection of bark and leaves for selling purposes was the main cause of threats. In the high mountains and high Himalayan regions, heavy grazing or over-grazing was also a serious problem. Therefore, more respondents (45) reported that over-grazing was the second most important cause of threats. Over grazing destroyed almost all the regeneration which would be the most serious issue for *Taxus wallichiana* for sustainable forest management.

Taxus wallichiana threat analysis was carried out in 3 important regions of Nepal i.e., medium hills, high mountains, and the high Himalayas because of the possible occurrence of *Taxus wallichiana* from medium hills to the high Himalayas (1000-4200 m). Due to the high demand of timber, the genus Taxus has been under heavy exploitation (Gajurel et al., 2014). Scores were assigned according to indicators designed by Wagner et al. (2008). We received the highest threat (> 25 = 26 = I) in the high mountains of Nepal due to heavy logging for construction as well as the collection of bark and leaves for selling to traders as medicinal plants (*Table 9*). In the Himalayan highlands of Nepal, this species is cut down to make houses or firewood. It is important that this species is linked to the livelihoods of people in the mountain and Himalayan regions of Nepal. They imposed to utilize this species for solving hand to mouth problems. The time has come to think for regular planting, sustainable harvesting and proper utilization or wise uses of *Taxus wallichiana* which leads this species for the long-term survival in the future courses of actions.

Conclusion

We concluded that the total suitable area for *Taxus wallichiana* in Nepal is 15781.59 km^2 (11% of the total area of Nepal). Of the total suitable area, 4350.59 km^2 (28%) of the area was inside the protected areas. The high mountain encompassed the largest suitable habitat followed by the middle mountain and the high Himalayas. Maximum Entropy (MaxEnt) software was used to predict the potential distribution or suitability using species origin points and 31 important environmental variables. Among the variables, elevation, isothermality (BIO-3), NDVI and land use/land cover were the most influential variables for generating the model. While analyzing the responsive curve, the maximum probability of the species (0.75) was at 4200 m. The result showed that elevation between 2000 and 4200 m was a good logistic output. The NDVI value increased to 0.8. Therefore, cultivation of this species is more suitable for temperate

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regions of Nepal. Isothermality of *Taxus wallichiana* received 52.5% with a probability of 0.79. This species favors cooler diurnal temperature, which was about half of the mean annual temperature of Nepal. For the land use/land cover, the highest probability (0.55) was received from forest type categories. We mostly recorded this species from the temperate regions of Nepal. The accuracy of the model was excellent with an average AUC of 0.96±0.002 and an average TSS of 0.66±0.038. Out of 77 districts of Nepal, the high majority (56 districts) were suitable for *Taxus wallichiana* so that we might initiate various cultivation projects in these areas. Due to its high medicinal properties, this tree is difficult to protect in its natural habitat. The collection of bark and leaves for selling purposes to traders was the major threat of *Taxus wallichiana*. Likewise, over-grazing, heavy uses in construction, and lack of awareness were also the major issues associated with threats of *Taxus wallichiana*.

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APPENDIX

Table 10. *Recorded occurance points of Taxus wallichiana during field visits in Nepal*

S.N.	Y	X	Altitude	Place	District
1	28.123147	85.318509	2699	Thulo Barkhu	Rasuwa
2	28.117123	85.328933	2694	Thulo Barkhu	Rasuwa
3	27.944737	85.904884	2758	Tatopani	Rasuwa
4	27.963047	85.898094	2731	Tatopani	Rasuwa
5	27.787033	85.386968	2173	Shivpuri	Kathmandu
6	27.806587	85.369226	2349	Shivapuri	Kathmandu
7	27.748915	85.247218	1689	Nagarjun	Kathmandu
8	28.029346	85.516631	2994	Helambu	Sindhupalchwok
9	27.955556	85.670976	2567	Near Thampakot	Sindhupalchwok
10	27.953359	85.68111	2594	Near Thampakot	Sindhupalchwok
11	27.720229	86.036668	2421	Suspa	Dolakha
12	27.73071	86.044324	2467	Suspa	Dolakha
13	27.757104	86.119085	2221	Babare Ban	Dolakha
14	27.688821	86.723901	2709	Lukla	Solukhumbu
15	27.639476	87.297373	2467	near chayasekharka	Sankhuwasabha
16	27.701793	87.306683	2482	Upper chayasekharka	Sankhuwasabha
17	27.680501	87.334841	2564	Kharka gaun	Sankhuwasabha
18	27.581084	87.179987	2468	Karka Gaun	Sankhuwasabha
19	27.622122	87.233685	2161	Tasigaun	Sankhuwasabha
20	27.629459	87.225452	2340	Near by Tasigaun	Sankhuwasabha
21	27.645285	87.225388	2422	Nearby Tasigaun	Sankhuwasabha
22	27.665147	87.231974	2776	Nearby Tasigaun	Sankhuwasabha
23	27.639936	87.212577	3044	Dandakharka	Sankhuwasabha
24	27.764071	87.334638	2371	Hatiya	Sankhuwasabha
25	27.755325	87.312503	2630	Near Hatiya	Sankhuwasabha
26	27.509364	87.031302	2336	near Sisuwawkhola	Sankhuwasabha
27	27.274662	86.896135	2307	Sapsu Dhap	Sankhuwasabha
28	27.236614	87.065434	2092	Halaucha	Bhojpur
29	27.291087	87.067927	2183	Boya	Bhojpur
30	27.137306	87.414229	2062	Tinjure	Dhankuta
31	27.145023	87.405995	2306	Tute	Dhankuta
32	27.155575	87.444033	2003	Basantapur	Tehathum
33	27.044421	87.349434	2171	Gurasedanda	Dhankuta
34	27.104269	87.916579	2931	Chhintapu	Ilam
35	27.101977	87.898547	2536	nearby Chhintapu	Ilam
36	27.137163	87.917433	2017	Sidin	Panthar
37	27.347938	87.991544	2981	Kalikhola	Taplejung
38	27.343007	87.974201	2688	Kalikhola	Taplejung
39	27.416179	87.758295	3037	Way to Pathibhara tample	Taplejung
40	27.424219	87.766388	3465	Way to Pathibhara tample	Taplejung
41	27.409913	87.755897	2876	Way to Pathibhara tample	Taplejung
42	27.359024	87.726443	2375	Tallophedi	Taplejung
43	27.663865	87.786682	3201	Olangchunggola	Taplejung
44	27.654117	87.809751	3295	way to olangchungdola	Taplejung
45	27.519794	87.78837	2034	lepchung	Taplejung
46	27.615866	85.093533	2132	Damon area (Risheshwor)	Makawanpur
47	28.254063	83.129375	2179	Heel	Baglung
48	28.540333	83.531383	2826	Chimkhola	Myagdi

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S.N.	Y	X	Altitude	Place	District
49	28.504773	83.5277	2698	Chimkhola	Myagdi
50	28.543393	83.52874	2617	Chimkhola	Myagdi
51	28.407931	83.700176	2708	Ghorepani	Kaski
52	28.402638	83.693022	3029	Ghorepani	Kaski
53	28.395289	83.692507	3110	Ghorepani	Kaski
54	28.333711	83.682018	2557	Lespark	Parbat
55	28.337723	83.7033194	2619	Lespark	Parbat
56	28.250256	83.80321	1813	Pachase area	Kaski
57	28.229258	83.792515	2321	Pachase area	Kaski
58	28.243274	83.797316	2005	Pachase area	Kaski
59	28.459383	83.829831	3303	Gandruk	Kaski
60	28.439634	83.842757	2319	Gandruk	Kaski
61	28.450902	83.842755	2713	Gandruk	Kaski
62	28.403621	83.841624	2339	Gandruk	Kaski
63	28.338544	84.260899	2090	Bhujung	Lamjung
64	28.332364	84.332364	1820	Bhujung	Lamjung
65	28.351417	84.256954	2521	Bhujung	Lamjung
66	28.360881	84.256703	2798	Bhujung	Lamjung
67	28.159165	84.932987	2566	Kashigaun	Gorkha
68	28.207445	84.912505	2603	Kashigaun	Gorkha
69	28.217557	84.93027	3099	Kashigaun	Gorkha
70	28.237611	84.935245	2660	Kashigaun	Gorkha
71	28.190595	84.913403	2345	Kashigaun	Gorkha
72	28.278267	84.848673	1948	Uhiya	Gorkha
73	28.297402	84.843931	2632	Uhiya	Gorkha
74	28.304785	28.304785	2680	Uhiya	Gorkha
75	28.310301	84.81535	3047	Uhiya	Gorkha
76	28.294582	84.816585	2981	Uhiya	Gorkha
77	28.284736	84.823146	2806	Uhiya	Gorkha
78	28.052233	85.166075	2630	Dandagaun	Rasuwa
79	28.083481	85.154509	2305	nearby Dandagaun	Rasuwa
80	28.062542	85.104	2534	Near Salme	Rasuwa
81	28.259079	84.637598	2414	Dudhpokhari	Lamjung
82	28.273113	84.603438	3064	Dudhpokhari	Lamjung
83	28.497203	83.279586	2890	Muna	Myagdi
84	28.595415	83.261067	3076	Gurja	Myagdi
85	27.991291	85.077599	2128	Sergang	Nuwakot
86	28.195818	84.916255	2534	Kashigaun	Rasuwa
87	28.203954	84.933885	2729	Kashigaun	Rasuwa
88	28.221888	84.795423	2243	Laprak	Gorkha
89	28.225988	28.225988	2004	Laprak	Gorkha
90	28.190576	84.838569	2196	Kashigaun	Gorkha
91	28.267378	84.695993	3073	Ghyachwok	Gorkha
92	28.299109	84.575459	2569	Dhodeni	Lamjung
93	28.23296	84.558376	2923	Lipu hill	Lamjung
94	27.509963	87.117845	2034	Ramite	Sankhuwasabha
95	27.77847	87.33404	2852	Hatiya	Sankhuwasabha
96	27.40027	87.805525	2364	Near Phawa Khola	Sankhuwasabha
97	27.519756	87.708005	2661	Ikhabu	Sankhuwasabha
98	27.016227	86.618526	2062	Near Nametar	Sankhuwasabha
99	28.191491	84.91342	2341	Kashigaun	Gorkha

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S.N.	Y	X	Altitude	Place	District
100	28.200042	84.920132	2839	Kashigaun	Gorkha
101	28.185965	84.904382	2229	Kashigaun	Gorkha
102	28.240662	84.808667	2645	Gumda	Gorkha
103	28.331946	83.662331	2634	Kyang	Parbat
104	28.358497	83.925916	2027	Ghachwok	Kaski
105	28.375098	83.927451	2516	Upallo Ghachwok	Kaski
106	28.173448	84.801784	2505	Umiya	Gorkha
107	27.775701	85.46722	2338	Bagdwars	Kathmandu
108	27.837207	85.450247	2023	Borlangbhanjyang	Kathmandu
109	27.062595	87.813596	2631	Near Pauwa Bhanjyang	Panchthar
110	27.063629	87.797225	2508	Near Pauwa Bhanjyang	Panchthar
111	27.148651	87.397162	2280	Tinjure	Dhankuta
112	27.651682	87.308859	2828	Bhaisi Kharka	Sankhuwasabha
113	27.65479	87.269933	2666	Near Baisi Kharka	Sankhawasabha
114	27.704535	86.722726	2827	Cheplung	Solukhumbu
115	27.548896	86.573957	2550	Phaplu	Solukhumbu
116	27.577001	86.558424	3003	Khamje	Solukhumbu
117	27.507279	85.491424	2362	Dhunkharka	Kavre
118	27.505614	85.475287	2387	Dhunkharka	Kavre
119	27.543765	85.442268	2590	Near Bhumidanda	Kavre
120	27.545295	85.421957	2470	Near Maningkhel	Kavre
121	27.711004	86.036949	2225	Suspakshepawati	Dolakha
122	27.722803	86.042529	2293	Suspakshepawati	Dolakha
123	28.323019	84.228065	2566	Bhujhung	Lamjung
124	28.354922	84.193958	3130	Mathillo Bhujung	Lamjung
125	28.319651	84.297973	2113	Ghanpokhara	Lamjung
126	28.297367	84.237455	2094	Upper Pasgaun	Lamjung
127	27.620938	87.112176	2778	Arun Valley	Tehrathum
128	27.667227	86.405298	3643	Chucure	Solukhumbu
129	27.512894	87.831241	2742	Tapethok	Taplejung
130	27.556221	85.974663	2912	Khola Kharka	Ramechhap

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