



INTERPOLATED ALTITUDINAL SPECIES RICHNESS IN ARGHAKHACHI DISTRICT OF NEPAL

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ABSTRACT

The magnitude of climatic variables over space and time determines the altitudinal variation of species richness. The present study has been carried out to determine the vascular plant species richness patterns along with altitude in the Arghakhanchi district (27° 45' to 28° 06' N and 80° 45' to 83° 23' E), West Nepal. The published literature related to the altitudinal distribution of vascular plant species in Arghakhanchi district was collected and enlisted a total of 597 species. The altitudinal range of the Arghakhanchi district was 200-2300 meters above sea level (masl) which was divided equally into 21 bands of 100 m each. The total number of vascular species that occurred at each 100 m contour elevation was considered as the species richness. The objective of this study was to find the vascular plant species richness pattern in Arghakhanchi district concerning altitude and climatic variables. The generalized linear model (GLM) was applied to the total species richness against altitude, annual mean temperature (AMT), and mean annual rainfall (MAR). Total vascular species richness showed a statistically significant unimodal pattern with a maximum richness of 471 species at 1300 masl ($r^2 = 0.91$; $p < 0.001$). Likewise, gymnosperm, dicot, monocot, and pteridophyte species richness showed a highly significant unimodal altitudinal richness pattern. Altitudes of modeled maximum species richness were found varied according to the taxa.

Keywords: Climate, Contour elevation, GLM, Linear, Unimodal

INTRODUCTION

Altitudinal variation in species richness is clearly expressed by area (Wang *et al.*, 2007), disparity of temperature and rainfall (Stevens & Fox, 1991; Khan & Ahmed, 2015), complex topography (Grytnes, 2003), aspect (Sharma *et al.* 2014), and soil composition (Dölarslan *et al.*, 2017). The relationship between altitude and species richness shows three types of patterns: monotonically increasing, decreasing, and hump-shaped (Rahbek, 1995; Song & Cao, 2017). More than 50 % of researches related to altitudinal richness showed a unimodal pattern with high richness at an intermediate altitude (Rahbek, 1995; Oommen & Shankar, 2005). There are numerous studies on species richness in Nepal which reported hump-shaped patterns with maximum richness at mid altitudes (Grytnes & Vetaas, 2002; Bhattarai *et al.*, 2004; Grau *et al.*, 2007; Baniya *et al.*, 2010). This hump-shaped pattern might not be prominent, particularly for small grain sizes and along incomplete gradients (Rahbek, 2005).

Mountains, an ideal natural system, provide gradients of climate and other environmental variables (Ghazal, 2015), harbor number of species (Gaston, 2000; Khan & Ahmed, 2015) and environment to explore drivers determining species richness patterns (Körner, 2007) due to wider altitudinal range and complex topography at a short space. Stevens (1989), in "seasonal variability hypothesis"

indicated that greater the seasonal temperature variations at high altitudes higher the species tolerant to greater climatic disparities. Biodiversity is not homogeneously dispersed across the earth (Khan *et al.*, 2016). The prime factors such as altitudinal gradients, aspects and the physical environment (Körner, 2000; Sharma *et al.*, 2014), climate, productivity, anthropogenic influences, evolutionary history, physiological traits and biotic interactions (Webb & Gaston, 2003; Zhang *et al.*, 2016) modify local microclimate and determine spatial and temporal distribution, abundance and richness patterns of organisms.

Species richness is the simplest and most frequently used (Brown *et al.*, 2007), predictable and fundamental measure of the community at both local and regional levels of diversity (Gotelli & Colwell, 2001). The height, diameter, and density of the species differed along the altitudinal gradient and showed a species-specific trend (Rana *et al.*, 2016). The distribution range of species and species richness pattern is changeable concerning time and space (Gillman & Wright, 2006). Species richness pattern appears as a combined picture of many ecological variables. The altitudinal range is the most important variable among all models at different scales which shapes patterns (Xu *et al.*, 2017).

The altitude itself represents a combination of other topographical factors such as aspect and slope (Holland &

Steyn, 1975), climatic variables like temperature, rainfall, etc. and edaphic properties (Ramsay & Oxley, 1997). Generally, the area decreases with the increase of altitude in the Himalaya region. Larger the area greater will be the number of species occupied (Lomolino, 2001) due to availability of more habitats or space, biogeographical provinces (Williams, 1964), and greater heterogeneity (Wills *et al.*, 2005). According to Bhattarai (2017), broad-scale explanatory variables cannot detect richness patterns at the finer scales and vice versa. Monotonic, unimodal, or multimodal patterns are common at local scales whereas unimodal pattern is favored for regional scales when multiple local replicates are aggregated (Oommen & Shanker, 2005). Even within the same mountain, organisms inhabiting different slopes may possess distinct diversity patterns and the underlying mechanisms (Shuai *et al.*, 2017).

Climatic factors vary with altitude, influence species richness patterns (Bhattarai, 2017). The physiological activities as productivity and life-form diversity are determined by the interactions between temperature and precipitation (O'Brien, 2002). Measurable changes in climate may occur only at distances greater than 100 km (O'Brien *et al.*, 1998), but environmental variation appears along the 100 m altitudinal differences (Bhattarai *et al.* 2004).

Variation in species richness with altitude either connected with the rate of change of eco-physiological processes or due to the change in temperature and productivity (Rahbek, 1995). Precipitation is relatively a complex gradient (Adler & Levine, 2007; Lomolino, 2001), that showed a spatial variation i.e., enhanced in some regions and decreased in some other mountainous regions. The altitudinal pattern in species richness has opened up ample options to find out the general mechanisms responsible for the distribution of biodiversity (Grytnes & McCain, 2007).

Nepal is a part of the central Himalayas where many unique biodiversity areas are yet to explore and proper conservation may be necessary. Arghakhanchi is one of the 77 districts, lies in the fifth province in Nepal and the high biodiversity zone of the mid-mountain region. The Humpbacked species richness-curve is a contingent rule for Community Ecology (Graham & Duda, 2011) which may be based on primary or secondary data. Different environmental factors act as the main driver of species richness at large and small areas (Vetaas & Ferrer-Castan, 2008). Thus this study puts the hypothesis that vascular species richness follows the unimodal pattern with altitude as well as climatic variables.

The main aim of this study was to determine the altitudinal species richness pattern of vascular and its derivatives richness pattern and relation with climatic variables.

MATERIALS AND METHODS

Study area

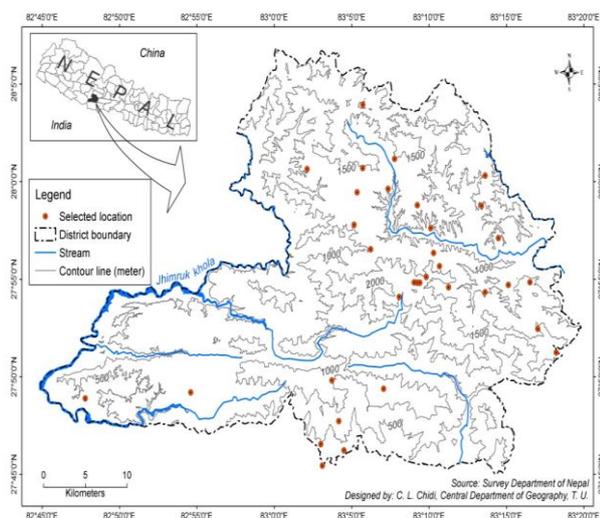
Arghakhanchi, one of the beautiful hilly districts, is located in Providence No. 5, west part of Nepal. It ranges from 27°45' to 28°06'N latitude and 80°45' to 83 ° 23' E longitudes (Map. 1). It covers an area of 1193 km² and a population of 197,632 (CBS, 2012). About 68 % of this district lies within the Mahabharat range and rest in the Siwalik hills. The altitude of this district ranges from 240 to 2515 masl (AEPC, 2016)). Physiographically, this district has four zones: lower tropical (less than 300 masl covers 0.2 %), upper tropical (300-1000 masl covers 51 %), subtropical (1000-2000 masl covers 49 %) and temperate zone (above than 2000 masl covers 0.2 %) (CBS, 2012). The average maximum and minimum temperatures range are between 25-27 °C in May-July and 5-7 °C in January (DHM, 2017). The average annual rainfall of this district remains around 1750 mm (MOAC/FAO, 2011). According to MOAC (2011), out of the total 119,300 ha land of the district, cultivable land occupies 45,712 ha (38 %), forested land occupies 66,800 ha (56 %), river and ponds occupy 5768 ha (4.8 %) and the residential area covers 1020 ha (0.85 %).

Lowlands, the southern part of Arghakhanchi, consists of the lower tropical forest of *Shorea robusta*, *Dalbergia sissoo*, *Lagestroemia parviflora*, *Terminalia alata*, etc. Churia sal forest lies between 300-1000 masl, dominated by *S. robusta*, *T. alata*, *Cassia fistula*, *Bauhinia variegata*, etc. In the middle belt, hill Sal forest is present with *Schima wallichii*, *Syzygium cumini*, *Pinus roxburghii*, and *Pyrus pashia*. In the northern aspect (below 1000 to 1500 masl), the broad-leaved forest (*Diospyrus malabarica*, *Rhododendron arboreum*, *S. wallichii*, *Catonopsis indica*) is intermixed with *P. roxburghii* and *S. robusta*. Between 1500-2000 masl, broad-leaved forest (*R. arboreum*, *S. wallichii*, *P. roxburghii*, *Myrica esculenta*) is present. The uppermost region (above than 2000 masl) in this district, the *Rhododendron - Quercus-Maesa* mixed forest is present which is dominated by *R. arboreum*, *Q. semecarpifolia*, *Q. glauca*, *M. esculenta*, *Zanthoxylum armatum* with bushes of *Maesa chisia*, etc (Panthi, 2005).

Study design and data collection

This study analyzed plant and climatic data collected from secondary sources described herein. Altitudinal distribution range of plants in the Arghakhanchi district was derived from different literature (Acharya *et al.* 2015; Fraser-Jenkins *et al.*, 2015; Fraser-Jenkin & Kandel, 2019; Panthi, 2005; Panthi & Chaudhary, 2002; Pokhrel, 2013; Poudel *et al.*, 2010). The altitudinal range (200-2300 masl) of Arghakhanchi district where plants were reported from was divided equally into 21 bands each with 100 masl intervals each. The species present in each 100 masl contour was considered as the species richness.

Similarly, species richness was categorized into dicot, monocot, gymnosperm, and fern or pteridophyte species richness. This is a macro-scale study that covered an entire altitudinal range of Arghakhanchi district.



Map 1. Arghakhanchi district with botanically explored sites

Annual mean temperature (AMT) and mean annual rainfall (MAR) data for Arghakhanchi district and surrounding areas obtained through published literature (MoAC, 2011; AEPC, 2016; DHM, 2017) were utilized in this study (Table 1). AMT per 100 altitudinal zone in this study was estimated after significant linear regression model ($R^2 = 0.99$; $p < 0.05$) at a lapse rate of $0.5^\circ \text{C}/100 \text{ m}$ (Bhattarai *et al.*, 2004). Rainfall was not a simple linear function of altitude, therefore a cubic smooth spline with 4 degrees of freedom was applied through the GAM model (Guisan *et al.*, 2002) to estimate total annual rainfall at each 100 m altitudinal bands.

Data analysis

The correlation among variables was estimated by using Pearson's Correlation method (Kassambara, 2018). The regression analysis of species richness against altitude was done by using the GLM (Hastie & Pregibon, 1993). Likewise, regression analysis of species richness was done against climatic variables such as MAR and AMT. The quasipoisson family of error distribution was applied to remove overdispersion. All these analyses were done in R (R Core Team, 2019).

RESULTS

Species richness of vascular plants

A total number of 597 vascular plant species (belonging to 452 genera and 190 families) were recorded in Arghakhanchi district (Table 2). The dicots consisted of 83.9 % species (157 families, 381 genera, and 501

species) while the monocot consisted of 13.9 % (24 families, 62 genera and 83 species), gymnosperm consisted of 0.5 % (2 families, 2 genera and 3 species), and pteridophytes (ferns) consisted of 1.7 % species (7 families, 7 genera and 10 species) as summarized in Table 2.

Table 1. Climatic records of Arghakhanchi and surrounding areas from 1994-2013 AD (MoAC, 2011; AEPC, 2016; DHM, 2017)

Place	Alt (m)	Lat ($^\circ$)	Lon ($^\circ$)	Amt ($^\circ\text{C}$)	Mar (mm)
Taulihawa	94	27.33	83.04	24.3	1357
Bhairahawa	109	27.31	83.26	24.2	1630
Patharkot	200	27.46	83.03	23.5	1467
Butwal	205	27.42	83.28	24	2203
Ghorai	701	28.03	82.3	22.1	1572
Tulsipur	725	28.08	82.18	22.4	1650
Bijuwar	823	27.52	82.52	22.2	1272
Tansen	1201	27.52	83.32	18.4	1912
Libang	1270	28.18	82.38	18.7	1312
Salyan Bazar	1457	28.23	82.1	19.2	987
Tamghas	1530	28.04	83.15	17.5	1897
Khanchikot	1760	27.56	83.09	16.4	1775

* Alt- altitude, Lat- latitude, Lon- longitude, Amt- annual mean temperature; Mar- mean annual rainfall

Table 2. Taxonomic diversity of vascular plants in Arghakhanchi district

Taxa	Species richness					Total
	Herb	Shrub	Tree	Climber	Fern	
Dicot	188	125	138	50	–	501
Monocot	70	4	1	8	–	83
Gymnosperm	–	–	3	–	–	3
Pteridophyte	–	–	–	–	10	10
Grand total	258	129	142	58	10	597

Correlation among variables

All vascular taxa showed positive but not significant relationship ($r = 0.11$ to 0.26 , $p < 0.001$) with altitude. Similar there was positive relationship between rainfall and vascular taxa except for monocot and gymnosperm (Table 3). But, the vascular taxa showed a negative and not significant relationship with temperature.

Species richness pattern of vascular plants against altitude

The species richness of vascular taxa (dicot, monocot, gymnosperm, and ferns) increased up to a certain altitude

then declined afterward showing a unimodal distribution pattern, as indicated by a statistically significant second-order model in *GLM* (Appendix 1). The total vascular species obtained the maximum modeled species 471

($R^2=0.914$ and $p < 0.001$) at peak elevation 1300 m (Fig. 1a). Similarly, the richness of dicot taxa (Fig. 1b), monocot (Fig. 1c), Gymnosperm (Fig. 1d), and ferns (Fig. 1e) made a hump-shaped structure against altitude.

Table 3. Correlation among species richness, altitude, temperature, and rainfall ($p < 0.001$)

	Altitude	Temp	Rainfall	Gymno	Pterido	Monocot	Dicot	Total spp
Altitude	1	-	-	-	-	-	-	-
Temperature	-1	1	-	-	-	-	-	-
Rainfall	0.8	-0.8	1	-	-	-	-	-
Gymnosperm	0.26	-0.26	0.06	1	-	-	-	-
Pteridophytes	0.23	-0.23	0.12	0.89	1	-	-	-
Monocots	0.11	-0.11	-0.02	0.9	0.96	1	-	-
Dicot	0.2	-0.2	0.11	0.86	0.98	0.96	1	-
Total species	0.19	-0.19	0.09	0.87	0.98	0.97	1	1

Temp = temperature, Gymno = Gymnosperm, Pterido = Pteridophytes, spp = species

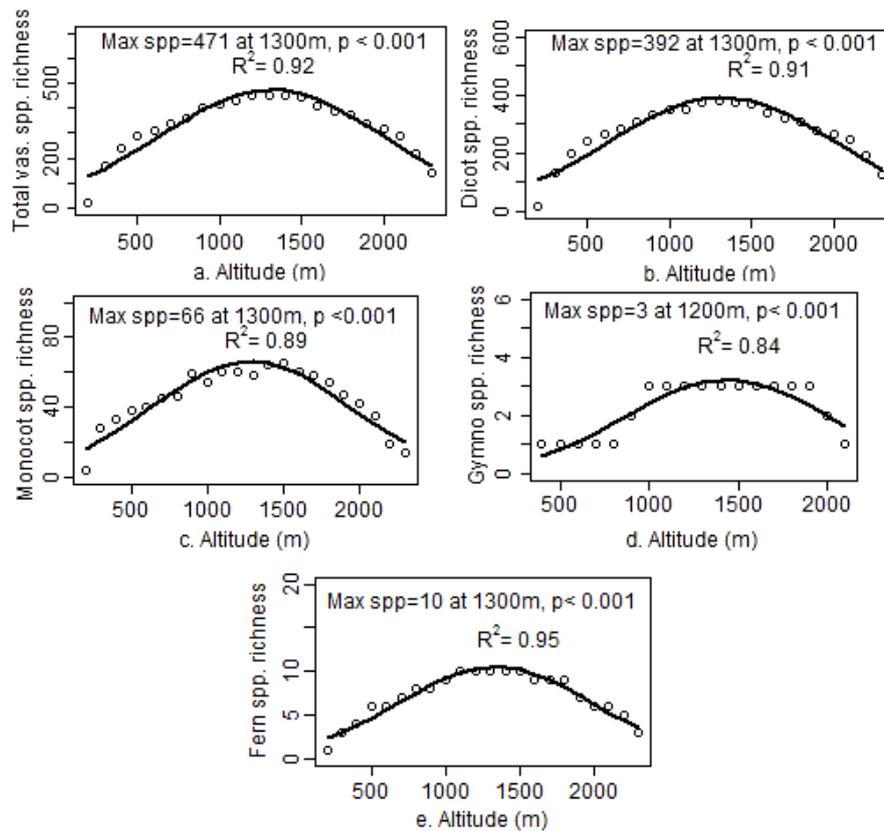


Fig. 1. Estimated response curves by GLM model, which portrays the relationship between altitude and species richness of (a) total vascular species (b) dicot (c) monocots (d) gymnosperm and (e) ferns

Species richness pattern against climatic variables

The richness pattern between vascular species and climatic variables (temperature and rainfall) was also unimodal, which was indicated by a statistically significant second-order term in *GLM* (Appendix 1). The

species richness increased along with the annual mean temperature (AMT) and decreased after optimum value 18.2 °C (at 1300 m) showing unimodal structure (Fig. 2a) bearing maximum modeled species 472 ($R^2=0.914$, $p < 0.001$). Similarly, the species richness showed unimodal

with plateau structure with mean annual rainfall (MAR) as depicted in Fig. 2(b) with maximum modeled species 432 at optimum value 1805.4 mm (at 900m, $R^2 = 0.64$ and $p < 0.001$).

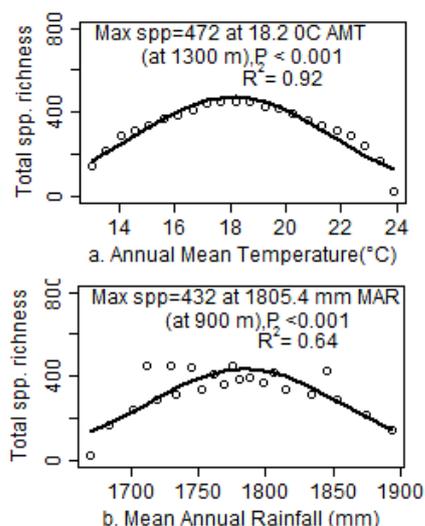


Fig. 2. Estimated response curves by the generalized linear model (GLM), which portrays the relationship between total species richness and (a) annual mean temperature (AMT) and (b) mean annual rainfall (MAR)

DISCUSSION

Species richness

Arghakhanchi is a biodiversity-rich district in Nepal due to the occurrence of 597 vascular species belonging to 452 genera and 190 families. This district covers 0.81 % of the total land area of Nepal (AEPC, 2016). It occupies 11.06 % of the total flowering species of Nepal (5309 species as reported by Rajbhandari *et al.*, 2017) and 1.87 % of the total pteridophytes (534 species reported by Fraser-Jenkins *et al.*, 2015) in Nepal. However, Panthi & Chaudhary (2002) reported a total of 501 flowering plants from the Arghakhanchi district. This number does not include the pteridophyte species. He increased the number of flowering plants as well as pteridophyte and may represent an increasing number of exploration from this district as well as other parts of the country. Based on these species we can say that the Arghakhanchi district rich in biodiversity though it is small in area. The species dominated and confined here are mainly of tropical to temperate origin.

Correlation among variables

There was a weak positive correlation among species richness variables of vascular taxa with altitude. This correlation was strong among species richness themselves: Gymnosperm, Pteridophyte, and Monocot

richness. The latter strong correlation among species would be the higher proportion of these species in the total richness. The result of empirical fern species richness and altitude (Jeyalatchagan *et al.*, 2019) and interpolated plant species richness with altitude (Grytness & Vetaas, 2002) was also found to be a positive relationship. The positive relationship between altitude and species richness may be due to an extend of altitude as well as a limit of the mountain. Since the altitudinal extent of Arghakhanchi was 200 to 2300 masl. Thus the positive relationship between altitude and richness was justified.

Similarly, rainfall showed a positive but temperature expressed a negative relation with species richness. Zhang *et al.* (2016) also found similar results that annual mean temperature (AMT) showed negative but rainfall showed a positive correlation against species richness at the temperate region of China. According to Sharma *et al.* (2009), altitude and climatic factors are the main regulating factors of distribution and show significant negative relation with species richness. The altitude itself represents a complex combination of related climatic variables with other environmental properties. Generally, environmental variables are measured at different units of scale. Each of these variables hardly shows a simple and direct linear relationship with species richness (Pitcher *et al.*, 2012). This means species richness may show nonlinear pattern with environmental variables.

Species richness pattern

From this study a significant unimodal species richness pattern against altitude was found. Similar patterns were observed for vascular plants (Grytness & Vetaas, 2002; Bhattarai & Vetaas, 2006), Bryophytes (Grau *et al.*, 2007), lichens (Baniya *et al.*, 2010), herbaceous plants (Bhatta *et al.*, 2018), and environmental variables (Pokharel *et al.*, 2018), etc. in central Nepal. The general unimodal species richness pattern was justified. During interpolation, the species present in an altitudinal band may create an artificial decrease in species richness towards both ends of the altitudinal gradient (Grytness & Vetaas, 2002). That may impose an artificial unimodal richness pattern. However, the altitudinal range of individual species in this study was beyond the extent of altitude of the landscape. Thus obtained unimodal richness pattern of this study is not an artifact. This result concludes that species richness of vascular plants has a unimodal pattern to altitude and climatic variables of the mountainous area, which was well portrayed by the fitted GLM.

In this study, greater number of species was present at 1200-1400 masl, which is less (1500 to 2500 for flowering plants and 1900 m for ferns) than overall Nepal (Grytnes & Vetaas, 2002). According to Bhattarai & Vetaas (2006), the range of species remains wider at mid-elevation and narrower at the gradient endpoints. Colwell

& Hunt (1994) explained that the mid-elevation peaks in species richness were formed by an increase of overlapping of species range towards the center of the domain. This helps to conclude that more or less mid-altitude of the overall distribution range bear maximum species richness.

The unimodal pattern of species richness may also be connected to human disturbance as well as disturbance associated with other factors. Arghakhanchi falls under the middle mountain range where human dominance is generally more than in higher altitudes. Middle mountain provides lots of opportunities and has been providing diverse ecological services to human from ethnomedicines (Rai & Singh, 2015) to several others (Bhandari *et al.*, 2018). That may support a finding of a unimodal relationship with altitude.

The climatic variables (temperature and rainfall) for total species graphed characteristically showed a significant unimodal pattern. Bhattarai *et al.*, (2004) found fern richness monotonically decreased towards higher (lowland) and lower (highland) values of the Potential Evapotranspiration (PET) gradient. The changes in temperature systematically alter the relationship between the biodiversity and ecosystem functioning via a temperature-driven shift in the strength of selection and complementary effects (Garcia *et al.*, 2018).

Similarly, species richness showed more strong correlation with temperature than rainfall, which was supported by the previous study of Griffiths *et al.* (2013). Temperature and rainfall variation occurs due to the altitudinal difference of mountains as well. Precipitation, a relatively complex pattern (Lomolino, 2001), is enhanced in some regions and decreased in other areas in the mountainous region. It has a significant impact on the productivity and species richness of the community (Yan *et al.*, 2015). The species richness of annuals, as well as perennial plants, may increase significantly with increasing annual and seasonal precipitation. Hence, Arghakhanchi lies relatively at the higher biodiversity zone in Nepal, favored by moderate disturbance, higher AMT, and MAR that support unimodal richness patterns.

The altitudinal distribution range was the most important predictor at all scales (Vetaas & Ferrer-Castan, 2008). It was supported that low peak elevation (1200-1400 m) in this study was proportional to less altitudinal distribution range (200-2300 m) of Arghakhanchi in comparison to overall Nepal (86 to 8848 m). Thus it is similar in species richness pattern but numerically different in peak elevation having the highest number of species to overall Nepal. The range margins of species in the gradient are determined directly or indirectly by unsuitable extremes of climatic factors (Bhattarai *et al.*, 2004) or geographical hard boundaries.

CONCLUSION

This study reported 597 vascular species in the Arghakhanchi district. The species richness showed a positive correlation with altitude and rainfall but a negative correlation with temperature. The species richness showed significant unimodal response with altitude, temperature, and rainfall. However, altitudes of the highest richness were found significantly different with taxa and less than the general pattern as purposed for Nepal.

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APPENDIX 1. Complete regression of species richness by use of generalized linear model against altitude and climatic variables in Arghakhanchi district ($R^2 = 0.64$ to 0.95 , $p < 0.01$)

Model	Predictor	Response	D _f	ResidDev	D _f	Deviance	F	Pr(>F)
0	Altitude	Total species	22	362416				
2			20	327	2	362088	14782	< 2.2e-16
0	Altitude	Dicot species	22	245523				
2			20	280	2	245243	11634	< 2.2e-16
0	Altitude	Monocot	21	6213.5				
2			19	27	2	6186.5	2497	< 2.2e-16
0	Altitude	Gymnosp	17	15.1111				
2			15	1.4605	2	13.651	72.262	1.993E-08
0	Altitude	Ferns species	21	147.818				
2			19	1.92	2	145.9	796.39	< 2.2e-16
0	AMT*	Total spp	21	270206				
2			19	170	2	270036	19461	< 2.2e-16
0	MAR ^a	Total spp	21	270206				
2			19	376	2	269831	7156.4	< 2.2e-16

*AMT- Annual mean temperature, ^aMAR – Mean annual rainfall, all bold entries were accepted model