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 the 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 (Korner, 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 Bhattacharai (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 (Bhattacharai, 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 (Bhattacharai 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 Humbacked 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 197632 (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 variegate, 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-Jenkins & 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°C/100 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.

| Place          | Alt (m) | Lat (°) | Lon (°) | AMT (°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     |
| Tulipsipur     | 725     | 28.08   | 82.18   | 22.4     | 1650     |
| Bijuwur        | 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     |

| Taxa            | Species richness |
|-----------------|------------------|
| Herb            | 188              |
| Shrub           | 125              |
| Tree            | 138              |
| Climber         | 50               |
| Fern            | –                |
| Total           | 501              |

| Taxa            | Species richness |
|-----------------|------------------|
| Herb            | 70               |
| Shrub           | 4                |
| Tree            | 1                |
| Climber         | 8                |
| Fern            | –                |
| Total           | 83               |

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 |

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

**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

Argakhanchi 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 Rajbandari 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 Arghakhachi 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; Bhattacharai & 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 Bhattacharai & 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. Bhattacharjee 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 (Bhattacharai 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 | \(D_t\) | Deviance | F | Pr(>F) |
|-------|-----------|----------|--------|----------|--------|----------|---|--------|
| 0     | Altitude  | Total species | 22 | 362416 |
| 2     | Altitude  | Dicot species | 20 | 327 | 2 | 362088 | 14782 | < 2.2e-16 |
| 0     | Altitude  | Monocot | 22 | 245523 |
| 2     | Altitude  | Gymnosp | 20 | 280 | 2 | 245243 | 11634 | < 2.2e-16 |
| 0     | Altitude  | Ferns species | 21 | 6213.5 |
| 2     | Altitude  | AMT* | 19 | 27 | 2 | 6186.5 | 2497 | < 2.2e-16 |
| 0     | Altitude  | MAR* | 17 | 15.1111 |
| 2     | Altitude  | Ferns species | 15 | 1.4605 | 2 | 13.651 | 72.262 | 1.993E-08 |
| 0     | AMT* | Total spp | 21 | 147.818 |
| 2     | AMT* | Total spp | 19 | 1.92 | 2 | 145.9 | 796.39 | < 2.2e-16 |
| 0     | MAR* | Total spp | 21 | 270206 |
| 2     | MAR* | Total spp | 19 | 170 | 2 | 270036 | 19461 | < 2.2e-16 |

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