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Altitude as a Major Factor Influencing the Distribution of Medicinal Plant Species in Mountain Damota, Wolaita South Ethiopia

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1. Abstract

Globally degradation of forest biodiversity has been one of the major serious environmental and socioeconomic concerns. In Ethiopia, the mountain environment which is one of the bases for ecologically, economically and socially important biodiversity has been degraded in the past three to four decades. In this study we assessed the richness and spatial distribution of two important indigenous medicinal plant species in mountain Damota, Wolaita Ethiopia. To collect the data a 20x20m plot size was established along with eight systematically laid transect lines and in each plot, the abundance and distribution of *Hagenia abyssinica* (Bruce) J. F Gmel (tree) and *Pentas schiperiana* Vatke (shrub) were assessed. The richness and distribution of the tree were evaluated by counting seedlings, saplings, and mature trees, whereas, the shrub was assessed by counting all observed individuals in each plot. From the overall 131 plots assessed, a total of 485 medicinal trees and 760 shrubs were collected. It was identified that the pattern of distribution of the individuals increased while the altitude increased and the highest richness of the individual was recorded at an altitude range between 2332 and 2661m.a.s.l. However, below 2320m.a.s.l. the number of both species decreased indicating either the ecological preference of the species or the extent of the extraction or influences of the local community surrounding the mountain that influenced the individuals. Finally, we recommend management intervention for the socially important species under threat on the mountain landscape.

2. Keywords: Abundance; Distribution; Indigenous medicinal plants; Richness; *H.abyssinic*; *P. schiperiana*; Socio-economic importance.

3. Background of Study

The wide range of favorable ecological, climatic, and edaphic conditions given Ethiopia rich resources of biodiversity (Tsegaye 1997; Dalelo 2011; Hussein 2021). These diverse physiographic and climatic conditions endowed the country with various faunal and floral resources though most resources are exploited unsustainably, and reduced in diversity and quality. The degradation of forest biodiversity has been one of the major serious environmental concerns in the country. The destruction was mainly caused by overuse associated with rapid population growth (2.7% per annum) (World Bank 2002); cattle ranching, and heavy logging (Oljirra 2019). In the country agricultural expansion, overgrazing, absence of community involvement and unstable institutional arrangement in combination with weak government institutions have resulted in the depletion of forest cover (Houghton 1994; Tadesse et al., 2014; Alemneh et al., 2019; Bufebo and Elias 2021; Yami and Mekuria 2022). Consequently, between 1990 and 2015, Ethiopia lost 18.6% (28,180 km^2) of its forested area (Young et al., 2020), which requires about $54 billion over a 30-years to restore the degraded and/or converted to other land use types from forests (Gebreselassie et al., 2016).

Decades ago, Ethiopian vegetation ecosystems deforested 62,000 ha annually (World Bank 2001). Recovering from the century-long degradation which dropped the forest coverage of the country to less than 3% (Zeleke and Hurni 2001; Ango et al., 2020; Berry 2003), the latest data about the forest coverage status of Ethiopia shows that the country owns the forest cover of 10–30% (FAO 2010). Recently, Ethiopians have started a restoration of degraded forest land in the form of a nationwide campaign of plantation named the 'green legacy' (Lemenih and Kassa 2014). Moreover, as an effective and sustainable land management strategy and restoration of degraded lands, different techniques of the restoration including area exclosure, integrated soil and water conservation, and participatory watershed management have been used to recover a million of hectares of deforested lands for the support of the climate change-resistant green economy (Pistorius et al., 2017; Moges et al., 2021). Despite there has been a considerable plantation effort led by the central government to restore the degraded lands by planting billions of seedlings every rainy season in the country, locally important indigenous species require focus in the process of restoration. Since the objectives of plantation forest and restoration of degraded lands vary from timber or non-timber production, watershed management, and more recently, carbon sink, the indirect effects of the process on biodiversity, however, are poorly understood (Bremer and Farley 2010). Consequently, the native animal and vegetation of the area is susceptible (Kaur et al. 2010), or disappearing at an alarming rate (Chen et al. 2016); which requires management interventions. Therefore, our goal should focus on the restoration of the ecologically and socioeconomically important species in the restoration processes of degraded lands (Norton 1998).

As the forms of availability of plants at different environmental conditions vary as it is subjected to abiotic and biotic factors (Pellissier et al. 2013); understanding the status of distribution of species is essential for developing efficient management strategies for threatened plant species (Ourge et al. 2021). In the era of changing climate, studying the patterns of plant species distribution at different environmental gradients is useful for envisaging future species assemblages (Frate et al. 2018); sustainable forest ecosystem management (Teshome et al. 2020); easing the extent of disturbance (Hailemariam and Temam 2020) and it's a useful mechanism for landscape management and conservation strategies (Rosas et al. 2021).

In Ethiopia, the land cover change resulted from the expansion of the cultivated lands which shifted the land covers to more agro-ecosystem and less cover of natural vegetation (Maitima et al. 2009). Therefore, medicinal plants which needed for a healthy forest ecosystem (Chamberlain et al. 2019) and are socioeconomically important (Sher etal. 2017) needs significant national attention in Ethiopia as they are rooted in indigenous knowledge systems (Astutik et al. 2019) and easily available to support the livelihoods of local people. This study, therefore, attempted to evaluate the richness of plants in an area and the patterns of the spatial distribution of two locally important indigenous medicinal plants on the mountain landscape in order to recommend the *in situ* and *ex-situ* strategies of conservation of the species in the study areas.

We used different factors to hypothesize for deciding the patterns of plant species distribution and richness such as disturbance by animals, farmlands expansion, settlement, collection by the local community, and topographic factors mainly the altitude and aspect. The first hypothesis (H_1) assumes that variations in the anthropogenic and edaphic factors do not affect the abundance of tree species in various forest layers. The second hypothesis (H_2) assumes that the anthropogenic and edaphic factors determine the shrub medicinal plant used in the study. These assumptions are supported by (Gough et al. 1994; Rahman et al. 2021) which they argued about factors that affect patterns of species distribution.

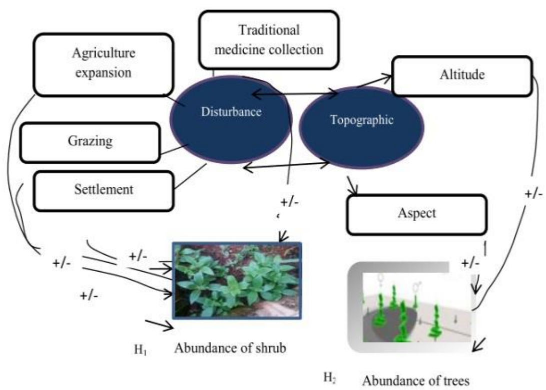

Figure 1: Hypotheses to predict plant species abundance in relation to multiple factors (disturbance and topography) in mountain Damota Wolaita, Ethiopia.

4. Materials and Methods

4.1. Description of the study area

The study was conducted at the highest mountain found in the Wolaita area named Damota found in South Ethiopia. The mountain Damota is bounded by different administrative Woredas (third level of administrative divisions) such as Damote Gale, Boloso Sore and, Sodo Zuria. Geographically, the study area is found between 6.89°-7.11° N latitude 37.75 -38° E longitude and 390km south of Addis Ababa. It is altitude ranges from 1501 -2958 meters above sea level and the peak area ended at Silasie church (Figure 2).

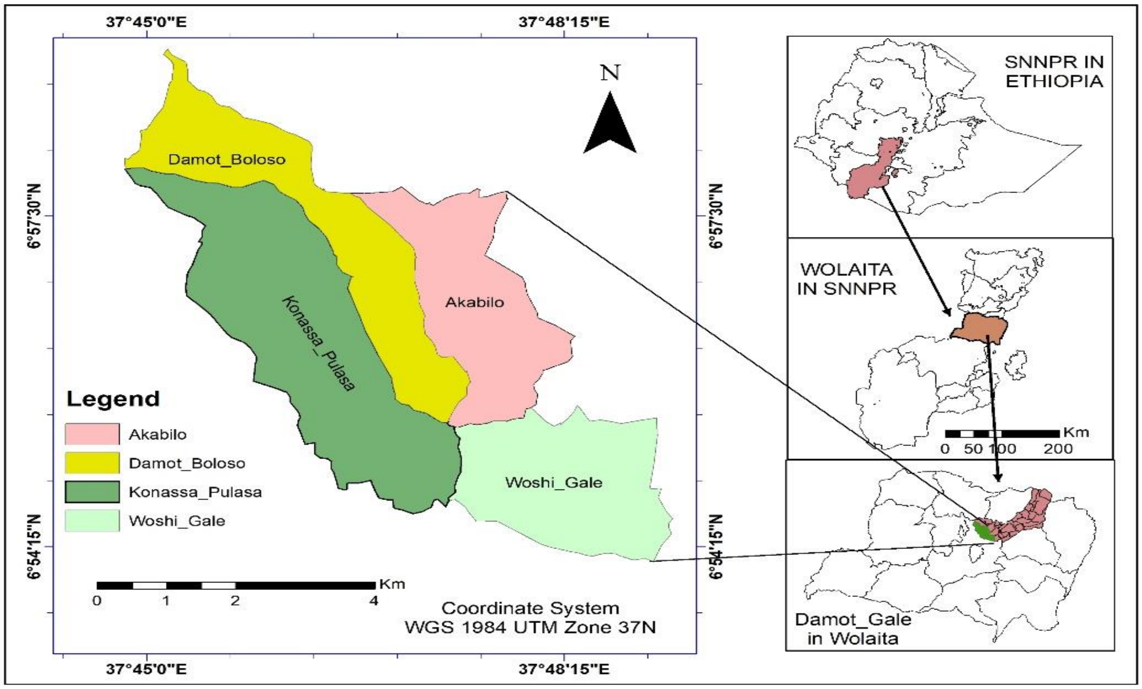

Figure 2: Study area map.

4.2. Climate

The mean annual temperature of the Damota area varies from 16c^0 to 19.9c^0 and the annual monthly temperature varies throughout the year from 16c^0 to 19.7c^0. The absolute maximum temperature occurs in mid-March and is about 28c^0 and the minimum temperature occurs in November and is about 10.8c^0. The annual mean rainfall is around 1375 mm **(**DGWAO 2019 and MDC 1985 to 2004).

4.3. Geology of the study area

The mountain where this study was conducted was formed by the volcanic activity in the Tertiary which occurred on the western edge of the Great Rift Valley that erupted in the Pleistocene epoch and is made from the accumulation of Rhyolitic lavas (Hutchison et al. 2016), exposed the environment to erosion in the humid climate and forest cover creating various small valleys created by the rivers (Gal and Moliner 2006).

4.4. The type of vegetation

Based on the data obtained from Wolaita Zone and Damote Gale Woreda Agricultural office (2019) the vegetation of the Damota area has been exploited for agriculture, pasture, timber, firewood, construction, etc. The remnant natural vegetation including *Hagina abyssinica, Juniperus procera, Olea africana, Podocarpus falcatus,* and *Croton mycrostachs* are sparsely distributed in different parts of the mountain. The mountain has been severely degraded by anthropogenic pressures over the past 50 years, resulting in an almost total loss of high forests in the region, and associated environmental impacts including loss of topsoil and soil quality resulting from erosion, flooding, and drought conditions. The vegetation restoration of the mountain started in the millennium by an international NGO named World Vision Ethiopia through the "Carbon Project". This intervention has increased vegetation restoration (Solomon et al. 2022).

4.5. Methods of data collection

As the rectangular quadrat is the best suited shape for studying the mountainous ecosystem for assessing vegetation, (Hussain et al., 2019; Dale and MacIsaac, 1989), in this study rectangular quadrats were used to assess the distribution and abundance of *Hagenia abyssinica,* and *Pentas schimperiana vatke,* after conducting the preliminary assessment. A total of eight transect lines were laid in parallel in the study area, consecutive plots were placed at a distance of 50m intervals and the length of the transect lines ended at the end of the forest. Accordingly, a total of 131 plots measuring 20×20m were placed at the interval of 250m apart. In each plot, *P. schimperiana* species was counted, and the *H. abyssinica* was counted for its seedlings, saplings and trees. Moreover, the topographies mainly aspects and altitude were recorded using Garmin GPS in all quadrats. The anthropogenic pressure and grazing at each quadrat were measured on a scale of (1-3: highly, moderately, and least disturbed) focusing on the fuelwood and medicinal plants extraction (Manan et al. 2020).

4.6. Data analysis

The data collected was analyzed by using vegetation survey and analysis methods such as relative density, frequency, and the results of the findings are presented in the form of figures, numbers, and graphs. Additionally, the Structural Equation Model was used to evaluate the impacts of ecological and disturbance-related factors on the abundance and distribution of selected medicinal plants by using R 4.0.2. and drawn sketch following (Ahmad et al., 2021). Moreover, Pearson's correlation analysis was used to explore the association between the main variables (impacts of variation in topography and patterns of disturbance) and species distribution, the human induced disturbance, grazing pressures, and the topographic factors. Moreover, the altitude interpolation by using the Inverse Distance Weighting (IDW) techniques was used by following the elevation and the occurrences of each individual.

5. Results and Discussion

5.1. Abundance and distribution of species along environmental gradients

Over the past decades mountain forests in Ethiopia has undergone extensive conversion, degradation, and fragmentation due to the increasing demand for timber and non-timber forest products, agricultural expansion, and unsustainable resource extraction. Consequently, the quantity and quality of mountain forests have been reduced and today a few remnants remain (Uhlig 1988; EFCCC 2020; Badesso et al. 2020). Among the forest tree and shrub species, medicinal plants are the most threatened by overutilization and other anthropogenic causes (Moges and Moges 2019).

In the current study, the distribution of important medicinal plants in the mountain ecosystem in the Wolaita area showed decreasing along environmental gradients. In the study areas species distribution increased while the altitude also increases and the highest abundance of the individuals was recorded at an altitude range between 2332 and 2661m above sea level. Above 2661m above sea level the species distribution and abundance reduced (Figure 3a-3d and Table 2). This could be due to the potentials of species adaptation to the environmental condition or the higher density and resulted pressure from humans and livestock on the plants species in lower elevations (Rokaya et al., 2012; Angelo and Daehler 2013).

There is some evidence that abiotic factors such as minimum temperature, precipitation, light availability, moisture, and soil nutrients have a direct impact on the distribution and abundance of species along altitudinal gradients (Jiang and Ma 2015; Potts et al., 2020; Liu et al., 2021; Blanco-Cano et al., 2022). Moreover, the change in the demography is the most important indirect driver for changing biodiversity (Mehring et al., 2020). For instance, the major challenge in the tropical mountains is a dense settlement and poor economical standards in the rural population (Burgess et al., 2007; Paudel et al., 2018; Liao et al., 2019).

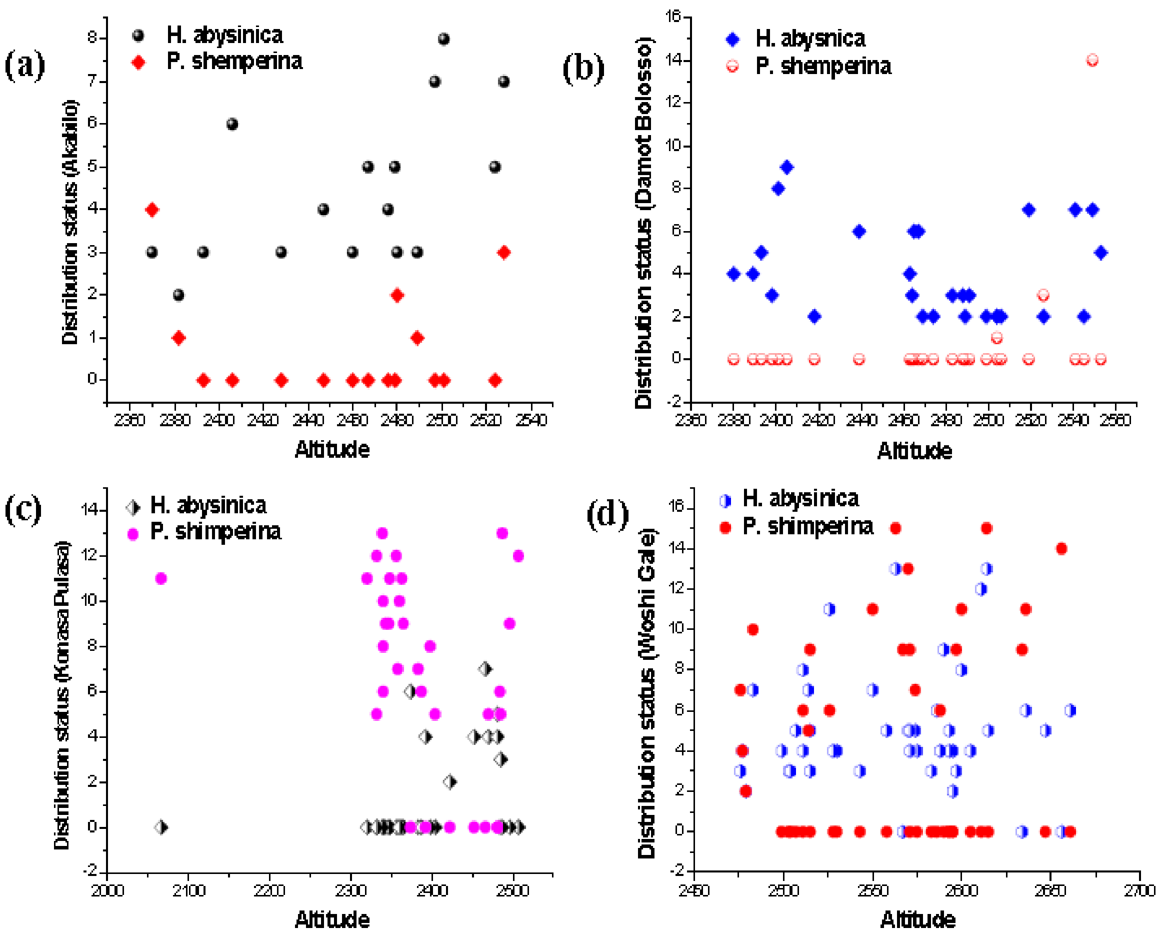

Figure 3: (a) Distribution patterns of individuals at Akabilo, (b) Damot Bolosso, (c) Konasa Pulasa, and (d) Woshi Gale districts of mountain Damota.

In the study areas, a total of 489 *H. abyssinica* in which (76 were seedlings, 144 saplings, and 299 trees) and 761 *P. schemperina* vatake were encountered at different altitudinal levels. The *H. abyssinica* individuals were more abundant at higher altitudes and the population increased with the increase in altitude (Kibonde et al., 2020; Assefa et al., 2010), indicating that the species *H. abyssinica* is dominant at higher altitudes (Kibonde et al., 2020). However, the distribution pattern of the species per hectare was 93 (Table 2), and due to its wide range of products and environmental benefits of *H. abyssinica,* (Assefa and Glatzel 2010), the sustainability of this important species is under threat.

Table 1: Pearson's correlation analysis of species abundance and altitude.

	H. abyssinica alt	*H. abyssinica Ab*	*P. schemperina alt*	*P. schemperin*a Ab
H. abyssinica alt	1			
H. abyssinica Ab	-0.0693	1		
P. schemperina alt	-0.4271	-0.0128	1	
*P. schemperin*a Ab	-0.0485	0.0625	0.1989	1

**H. abyssinica* alt =relationship of *H. abyssinica* to increment in altitude, H. abyssinica Ab= abundance of *H. abyssinica* at higher altitude, *P. schemperina alt*= relationship of *P. schemperina* to increment in altitude and *P. schemperin*a Ab = abundance of *P. schemperin*a at higher altitude

Pearson's correlation analysis results (Table 1) also indicated that above 2600masl species abundance has a negative significant relationship with altitude (Sinha et al., 2018). In the study area, both *P. schiperiana vatake* and *H. abyssinica* showed a negative relation with higher altitudes indicating that altitudinal variation influences the availability of the individuals.

In fact, it is important to account for multiple factors that may be related to plants' distribution patterns along elevation gradients (Song et al., 2016); the result of human pressure was clearly indicated by the distribution of the individuals as both types of species showed zero abundance at lower altitude of the mountain and observed very little number of individuals at the close premises to the local community. This type of strong human disturbance shows the need for immediate conservation of forest diversity (Yirga et al., 2019); to gain their goods and services for subsistence lifestyles (Shah and Cummings 2021) and the sustainability of the species (Chen et al., 2016; Rankoana 2016). As the medicinal plant's resources are highly used by Ethiopian communities to secure their subsistence and health (Assefa et al., 2010), measures of conserving the species are urgently required either in the form of area protection or domestication methods. The individuals from a shrub family (*P. schimperiana*) appeared at the water shores and under the canopy of big trees has shown a density of 146/ha in the study sites. This shows that the density of the species along the environmental gradient is limited requiring attention to conservation as the nature of intense utilization of species endangers the revival of the vegetation (Kefalew et al., 2015).

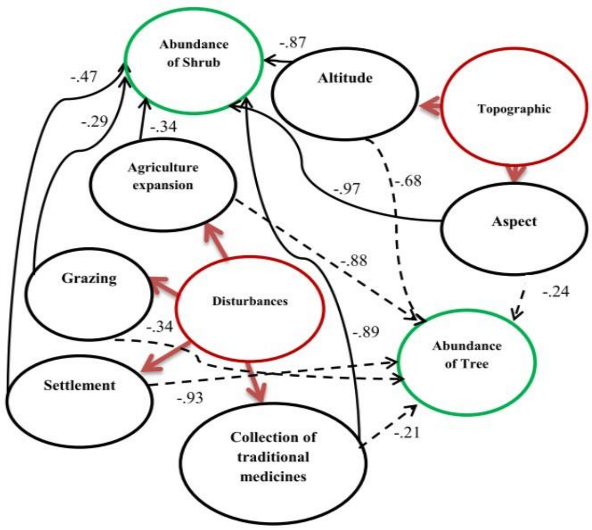

Figure 4: Structural Equation Modeling (SEM) revealing factors affecting the abundance and distribution of the species.

Moreover, the topographic features mainly aspect, slope, and elevation can impact local climate and soil conditions that results in effects on vegetation structure (Gaitán et al., 2014; Yang et al., 2020; Cho et al., 2017; Yang et al., 2020; Muhammed and Elias 2021), and in this study, the distribution of individuals varied at four study sites where the site situated at the east and southwestern showed a better pattern for both species (Figure 3b and 3d). It was identified that all the topographic and disturbance related factors have a negative impact on the abundance of both shrub and tree species; had a significant effect (Figure 4). The SEM model described R^2 (26%) with the Akaike Information Criterion (AIC) 191, χ^2 = 2.61, P=0. 001 and Goodness of Fit Index (GFI) value of 0.95.

On the other hand, it is necessary to manage mature trees to get their benefits of facilitation of natural regeneration under the canopy as tree canopies support the natural regeneration processes of species (Zhu et al., 2014; Baral and Ghimire, 2020; Hammond and Pokorný, 2021; Osuri et al., 2021; Liu et al., 2022).

5.2. Density and frequency of species in the plots studied

Studying the distribution patterns of individuals and the factors influencing them is important in the management strategies of natural resources (Kipkoech et al., 2019). It also helps to identify the focus areas of conservation (Zhang et al., 2016; Dibaba et al., 2022); to investigate the fate of the species in the current global change context (Rawat et al., 2021; Miller and Franklin 2002).

Table 2: The patterns of distribution of species at different altitudes.

Species name	Family name	Density /ha	R/Abundance	Frequency	Relative frequency	Relative density
H. abyssinica	Rosacea	93	37.3	83	45.35	38.9
P. schimperiana	Rubiaceae	146	58	98.9	54.64	61.08

Altitude is an important factor in habitat diversity because the availability of the resources such as heat and water varies along the vertical gradients (Wani et al., 2022; Pinto-Junior et al., 2020; Shimono et al., 2010; Körner 2000); which in results plant compositions variation at higher elevations on mountains areas (Lee et al., 2021; Bhat et al., 2022). In this study, it was identified that the relative density of both species were 45.35 and 54.64/ha (Table 2) indicating that environmental filtering acts as a key factor in the species distribution demanding the in situ- or ex-situ conservation for the sustainability of important medicinal species in the mountain Damota.

Among the four study areas where the study was conducted (Damot Boloso, Konasa Pulasa, Akabilo and Woshi Gale), Akabilo, and Woshi Gale have shown relatively better abundance of the species *H. abyssinica*. In the contrary, at the Konasa Pulasa site, there was few *H. abyssinica* individuals observed however, the *P. schimperiana* was observed in high number (Figure 3 b and d). These also revealed by results of the inverse distance weighting (IDW) techniques where altitude was used with the field survey data of species along the environmental gradients indicating the locations of the individuals and patterns of their distribution (Figure 5).

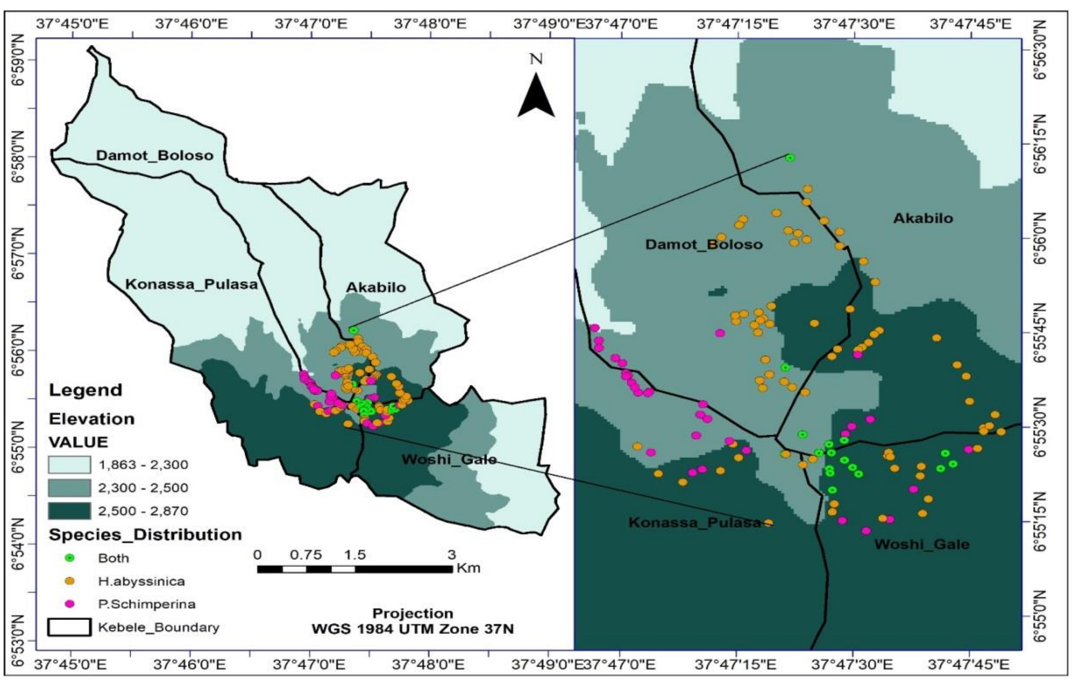

Figure 5: Distribution patterns of *H. abyssinica* and *P. schemperina* in the study area.

As everything becomes clearer when it is presented in a figure in the form of a model illustration (Rufino et al., 2021), except for the Akabilo, the other three sites were indicating relatively better distribution patterns of individuals of both species, however, Woshi Gale has more species distribution in the given altitudinal ranges (Figure 3d, 5 and 6).

The species were mostly observed at the sides of rivers and inaccessible areas indicating that the expansion of agriculture, deforestation or over exploitation, and over-grazing as principal threats to the medicinal plants. During the field visit and reconnaissance survey, some of the local communities were domesticating both species in their farmland in the form of agroforestry trees for their product and services values.

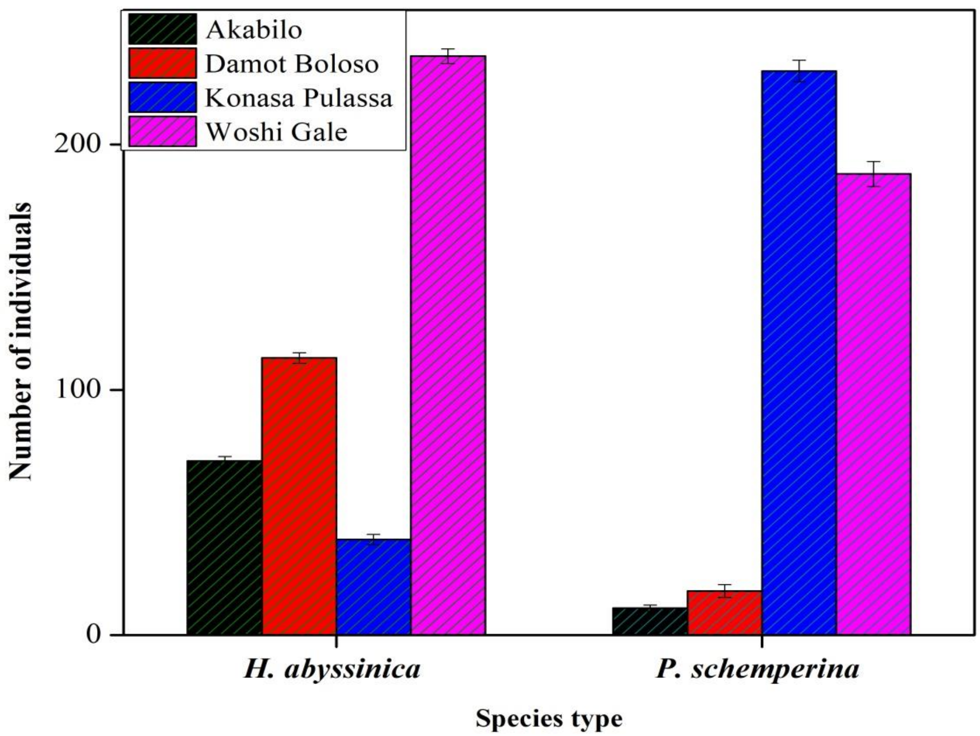

Figure 6: Species distribution at four specific study sites.

Studies show that traditional medicine and medicinal plants were faced with challenges notably (Kayombo et al., 2013; Rana et al., 2017; He et al., 2020; Yeboah et al., 2022), due to higher pressure on the use of the plants (Rokaya et al. 2012; Zhao et al., 2022), and the climate change affecting highly suitable habitats for the most important medicinal plants requiring the conservation priority areas (Silva et al., 2022). This study also confirms the same ideas and suggestions of management for the sustainability of *H. abyssinica* and *P. schimperiana* on mountain Damota watershed.

6. Conclusions

This study which was conducted by following the vegetation survey method indicates that the population of an important medicinal plants; *H. abyssinica* and *P. schimperiana* individuals were distributed at higher altitudes of mountain Damota. The findings of the study indicated that for both species anthropogenic and environmental filtering acts as the key factor in the individual distribution which suggests the ex-situ conservation to save the species from degradation leading to extinction. Moreover, Pearson's correlation indicated that the species *P. schiperiana vatake* and *H. abyssinica* have a negative relation with higher altitudes signifying that altitudinal variation influences the availability of the species besides the anthropogenic/demographic influences. Therefore, the conservation or management efforts should include considering the ecological relevance for the successful restoration, and management of the resources. Generally, from the hypothesis drawn, it was identified that both the anthropogenic and edaphic factors influenced the distribution and abundances of both species which disproves the H_1 where the anthropogenic and edaphic factors affect only the tree family.

Data availability

The datasets collected and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

The authors consent to publish the data included in this draft.

Competing interest

The authors declare that they have no conflict of interest.

Funding

There was no funding used for this study.

Authors' contributions

Dr. Tamirat selected the title, guided the development of the proposal, and research design, data collection methods, conducted the analysis, written the manuscript, Mr. Tadesse worked on the data collection and contributed to the data analysis, and Mr. Belete worked on the commenting and correction of proposal development and Prof. Moon and S. Jeong worked on the final write up and edition.

References

1. Ahmad Z., Khan SM., Page S., 2021. Politics of the natural vegetation to balance the hazardous level of

elements in marble polluted ecosystem through phytoremediation and physiological responses. Journal of Hazardous Materials 414: 125451.

2. Alemneh T., Zaitchik BF., Simane B., Ambelu A., 2019. Changing Patterns of Tree Cover in a Tropical Highland Region and Implications for Food, Energy, and Water Resources. Front Environ Sci 7: 1.
3. Angelo CL., Daehler CC., 2013. Upward expansion of fire-adapted grasses along a warming tropical elevation gradient. Ecography 36: 551-559.
4. Ango TG., Hylander K., Börjeson L., 2020. Processes of Forest Cover Change since 1958 in the Coffee-Producing Areas of Southwest Ethiopia. Land 9(8): 278.
5. Assefa B., Glatzel G., 2010. Measuring Soil Fertility under Hagenia abyssinica (Bruce) J. F. Gmel by the Biotest Method. International Journal of Agronomy 2010: 845087.
6. Assefa B., Glatzel G., Buchmann C., 2010. Ethnomedicinal uses of Hagenia abyssinica (Bruce) J.F. Gmel. among rural communities of Ethiopia. Journal of Ethnobiology and Ethnomedicine 6: 20.
7. Astutik S., Pretzsch J., Ndzifon Kimengsi J., 2019. Asian Medicinal Plants’ Production and Utilization Potentials: A Review. Sustainability 11(19): 5483.
8. Badesso BB., Madalcho AB., Mena MM., 2020. Trends in forest cover change and degradation in Duguna Fango, Southern Ethiopia. Cogent Environmental Science 6: 1834916.
9. Baral S., Ghimire P., 2020. Effect of tree canopy opening in the regeneration layer of Terai Sal (Shorea robusta Gaertn.) forest in Western Nepal: A case study. Tropical Plant Research 7(2): 502-507.
10. Berry L., 2003. Land Degradation in Ethiopia: Its Extent and Impact, Commissioned by the GM with WB Support.
11. Bhat JA., Kumar M., Negi A., Todaria N., Malik ZA., Pala NA., Kumar A., Shukla G., 2020. Species diversity of woody vegetation along altitudinal gradient of the Western Himalayas. Global Ecology and Conservation 24: e01302.
12. Blanco-Cano L., Navarro-Cerrillo RM., González-Moreno P., 2022. Biotic and abiotic effects determining the resilience of conifer mountain forests: The case study of the endangered Spanish fir. Forest Ecology and Management 520: 120356.
13. Bufebo B., Elias E., 2021. Land Use/Land Cover Change and Its Driving Forces in Shenkolla Watershed, South Central Ethiopia. The Scientific World Journal 2021: 9470918.
14. Burgess ND., Balmford A., Cordeiro NJ., Fjeldså J., Küper W., Rahbek C., Sanderson EW., Scharlemann JP., Sommer JH., Williams PH., 2007. Correlations among species distributions, human density and human infrastructure across the high biodiversity tropical mountains of Africa. Biological Conservation 134(2): 164-177.
15. Chamberlain J., Small C., Baumflek M., 2019. Sustainable Forest Management for Nontimber Products. Sustainability 9: 2670.
16. Chen SL., Yu H., Luo HM., 2016. Conservation and sustainable use of medicinal plants: problems, progress, and prospects. Chin Med 11: 37.

17. Cho Y., Lee D., Bae S., 2017. Effects of vegetation structure and human impact on understory honey plant richness: implications for pollinator visitation. J Ecology Environ 41: 2.
18. Dale T., MacIsaac MR., 1989. New Methods for the Analysis of Spatial Pattern in Vegetation.
19. Dalelo A., 2011. Loss of biodiversity and climate change as presented in biology curricula for Ethiopian schools: Implications for action-oriented environmental education. International Journal of Environmental & Science Education 7(4): 619-638.
20. Dibaba A., Soromessa T., Warkineh B., 2022. Plant community analysis along environmental gradients in moist afromontane forest of Gerba Dima, South-western Ethiopia. BMC Ecol Evo 22: 12.
21. Environment, Forest and Climate Change Commission. 2020 Trees, Forests and Profits in Ethiopia: An Assessment of Tree-Based Landscape Restoration Investment Opportunities in Ethiopia. Addis Ababa: EFCCC.
22. FAO., 2010. Global Forest Resources Assessment 2010. Country Report Ethiopia. Food and Agriculture Organization (FAO), Rome, Italy.
23. Frate L., Carranza ML., Evangelista A., Stinca A., Schaminée JH., Stanisci A., 2018. Climate and land use change impacts on mediterranean high-mountain vegetation in the Apennines since the 1950s. Plant Ecol Divers 1-13.
24. Gaitán JJ., Oliva GE., Bran DE., Maestre FT., Aguiar MR., Jobbágy EG., Buono GG., Ferrante D., Nakamatsu VB., Ciari G., Salomone JM., Massara V., 2014. Vegetation structure is as important as climate for explaining ecosystem function across Patagonian rangelands. Journal of Ecology 102(6): 1419-1428.
25. Gebreselassie S., Kirui OK., Mirzabaev A., 2016. Economics of Land Degradation and Improvement in Ethiopia. In: Nkonya E., Mirzabaev A., von Braun J. (eds) Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. Springer, Cham.
26. Gough L., Grace JB., Taylor KL., 1994. The Relationship between Species Richness and Community Biomass: The Importance of Environmental Variables. Oikos 70(2): 271-279.
27. Hailemariam MB., Temam TD., 2020. Pattern of Plant Community Distribution along the Elevational Gradient and Anthropogenic Disturbance in Gole Forest, Ethiopia", International Journal of Ecology 2020: 6536374.
28. Hammond ME., Pokorný R., 2021. Impact of Canopy Gap Ecology on the Diversity and Dynamics of Natural Regeneration in a Tropical Moist Semi-Deciduous Forest, Ghana. Biology and Life Sciences Forum 2(1): 10.
29. He Y., Xiong Q., Yu L., Yan W., Qu X., 2020. Impact of Climate Change on Potential Distribution Patterns of Alpine Vegetation in the Hengduan Mountains Region, China. Mountain Research and Development 40(3): R48-R54.
30. Houghton RA., 1994. The Worldwide Extent of Land-use ChangeIn the last few centuries, and particularly in the last several decades, effects of land-use change have become global. BioScience, 44(5): 305-313.
31. Hussain M., Khan S., Abd_Allah E., Ul Haq Z., Alshahrani T., Alqarawi A., Abdullah1–Ahmad H., 2019. Assessment of Plant communities and identification of indicator species of an ecotnal forest zone at durand line, district Kurram, Pakistan. Appl Ecol Environ Res 17(3): 6375-6396.

32. Hussein A., 2021. A Brief Review on Species Diversity, Regeneration and Conservation in Ethiopia. J Earth Sci Clim Change 12: 586.
33. Hutchison W., Fusillo R., Pyle D., 2016. A pulse of mid-Pleistocene rift volcanism in Ethiopia at the dawn of modern humans. Nat Commun 7: 13192.
34. Jiang Z., Ma K., 2015. Environmental filtering drives herb community composition and functional trait changes across an elevational gradient. Plant Ecol Evol 148: 301-310.
35. Kassa H., Abiyu A., Hagazi N., Mokria M., Kassawmar T., Gitz V., 2022. Forest landscape restoration in Ethiopia: Progress and challenges. Front For Glob Change.
36. Kaur R., Joshi V., Joshi SP., 2010. Impact of degradation on biodiversity status and management of an alpine meadow within Govind Wildlife Sanctuary and National Park, Uttarkashi, India, International Journal of Biodiversity Science, Ecosystem Services & Management 6(3-4): 146-156.
37. Kayombo EJ., Mahunnah RLA., Uiso FC., 2013. Prospects and Challenges of Medicinal Plants Conservation and Traditional Medicine in Tanzania. Anthropol 1: 108.
38. Kefalew A., Asfaw Z., Kelbessa E., 2015. Ethnobotany of medicinal plants in Ada'a District, East Shewa Zone of Oromia Regional State, Ethiopia. Journal of Ethnobiology and Ethnomedicine 11: 25.
39. Kibonde S., Augustino S., Mabiki F., 2020. Population Status of Hagenia abyssinica and Myrica salicifolia: A Reflection from Rungwe District, Mbeya Region, Tanzania. Open Journal of Ecology 10: 585-595.
40. Kipkoech S., Melly DK., Mwema BW., Mwachala G., Musili PM., Hu G., Wang Q., 2019. Conservation priorities and distribution patterns of vascular plant species along environmental gradients in Aberdare ranges forest. PhytoKeys 131: 91-113.
41. Körner C., 2000. Why are there global gradients in species richness? Mountains might hold the answer. Trends Ecol Evol 15: 513-514.
42. Lee MA., Burger G., Green ER., 2021. Relationships between resource availability and elevation vary between metrics creating gradients of nutritional complexity. Oecologia 195: 213-223.
43. Liao C., Luo Y., Tang X., Ma Z., Li B., 2019. Effects of human population density on the pattern of terrestrial nature reserves in China. Global Ecology and Conservation 20: e00762.
44. Liu J., Xu Y., Shan Y., Burgess KS., Ge X., 2021. Biotic and abiotic factors determine species diversity–productivity relationships in mountain meadows. Journal of Plant Ecology 14(6): 1175-1188
45. Liu F., Tan C., Yang Z., Li J., Xiao H., Tong Y., 2022. Regeneration and growth of tree seedlings and saplings in created gaps of different sizes in a subtropical secondary forest in southern China. Forest Ecology and Management 511: 120143.
46. Maitima JM., Mugatha SM., Reid RS., Gachimbi LN., Majule A., Lyaruu H., Pomery D., Mathai S., Mugisha S., 2009. The linkages between land use change, land degradation and biodiversity across East Africa. African Journal of Environmental Science and Technology 3(10): 310-325.

47. Manan F., Khan SM., Ahmad Z., 2020. Environmental determinants of plant associations and evaluation of the conservation status of Parrotiopsis jacquemontiana in Dir, the Hindu Kush Range of Mountains. Trop Ecol 61: 509-526.
48. Mehring M., Mehlhaus N., Ott E., 2020. A systematic review of biodiversity and demographic change: A misinterpreted relationship?. Ambio 49: 1297-1312.
49. Miller J., Franklin J., 2002. Modeling the distribution of four vegetation alliances using generalized linear models and classification trees with spatial dependence. Ecol. Model 157: 227-247.
50. Moges A., Moges Y., 2019. Ethiopian common medicinal plants: their parts and uses in traditional medicine ecology and quality control. In A. Gonzalez, M. Rodrigu ez., and N. G. Saglam (Eds.), plant science, structure anatomy and physiology in plant cultured in Vivo and in viro. Intechopen.
51. Moges Y., Haile M., Livingstone J., 2021. Integration of forest landscape restoration in Ethiopia's nationally determined contributions. A review, with a focus on drylands. PENHA, Addis Ababa, Ethiopia and Tropenbos International, Ede, the Netherlands. 66.
52. Muhammed A., Elias E., 2021. The Effects of Landscape Change on Plant Diversity and Structure in the Bale Mountains National Park, Southeastern Ethiopia. International Journal of Ecology 2021: 6628282.
53. Norton DA., 1998. Indigenous biodiversity conservation and plantation forestry: options for the future. New Zealand Forestry 43: 34-39.
54. Oljirra A., 2019. The causes, consequences and remedies of deforestation in Ethiopia. Journal of Degraded and Mining Lands Management 6(3): 1747-1754.
55. Osuri AM., Mudappa D., Kasinathan S., Shankar Raman TR., 2021. Canopy cover and ecological restoration increase natural regeneration of rainforest trees in the Western Ghats, India. Restoration and natural regeneration. Society for Ecological Restoration.
56. Ourge Wegasie M., Klanderud K., Totland Ø., Eldegard K., 2021. Ontogenetic niche shifts in a locally endangered tree species (Olea europaea subsp. cuspidata) in a disturbed forest in Northern Ethiopia: Implications for conservation. PLoS ONE 16(9): e0256843.
57. Paudel PK., Sipos J., Brodie JF., 2018. Threatened species richness along a Himalayan elevational gradient: quantifying the influences of human population density, range size, and geometric constraints. BMC Ecol 18: 6.
58. Pellissier L., Pinto-Figueroa E., Niculita-Hirzel H., Moora M., Villard L., Goudet J., Guex N., Pagni M., Xenarios I., Sanders I., Guisan A., 2013. Plant species distributions along environmental gradients: do belowground interactions with fungi matter?. Frontiers in plant science 4: 500.
59. Pinto-Junior HV., Villa PM de Menezes LFT., 2020. Effect of climate and altitude on plant community composition and richness in Brazilian inselbergs. J Mt Sci 17: 1931-1941.
60. Pistorius T., Carodenuto S., Wathum G., 2017. Implementing Forest Landscape Restoration in Ethiopia. Forests 8(3):61.
61. Potts LJ., Gantz JD., Kawarasaki Y., 2020. Environmental factors influencing fine-scale distribution of Antarctica's only endemic insect. Oecologia 194: 529-539.

62. Rahman A., Khan S., Ahmad Z., Alamri S., Hashem M., Ilyas M., Aksoy A., Dülgeroğlu C., Khan G., Ali S., 2021. Impact of multiple environmental factors on species abundance in various forest layers using an integrative modeling approach. Global Ecology and Conservation 29: e01712.
63. Rana SK., Rana HK., Ghimire SK., 2017. Predicting the impact of climate change on the distribution of two threatened Himalayan medicinal plants of Liliaceae in Nepal. J Mt Sci 14: 558-570.
64. Rankoana SA., 2016. Sustainable Use and Management of Indigenous Plant Resources: A Case of Mantheding Community in Limpopo Province, South Africa. Sustainability 8: 221.
65. Rawat B., Gaira KS., Gairola S., Tewari LM., Rawal RS., 2021. Spatial prediction of plant species richness and density in high-altitude forests of Indian west Himalaya. Trees, Forests and People 6: 100132.
66. Rokaya MB., Münzbergová Z., Shrestha MR., 2012. Distribution patterns of medicinal plants along an elevational gradient in central Himalaya, Nepal. J Mt Sci 9: 201-213.
67. Rosas YM., Peri PL., Lencinas MV., 2021. Improving the knowledge of plant potential biodiversity-ecosystem services links using maps at the regional level in Southern Patagonia. Ecol Process 10: 53.
68. Rufino MM., Albouy C., Brind'Amour A., 2021. Which spatial interpolators I should use? A case study applying to marine species. Ecological Modelling 449: 109501.
69. Shah M., Cummings AR., 2021. An analysis of the influence of the human presence on the distribution of provisioning ecosystem services: A Guyana case study. Ecological Indicators 122: 107255.
70. Sher H., Bussmann RW., Hart R., 2017. Promoting Sustainable Use of Medicinal and Aromatic Plants for Livelihood Improvement and Biodiversity Conservation under Global Climate Change, through Capacity Building in the Himalaya Mountains, Swat District, Pakistan. Ann Mo Bot Gard 102: 309-315.
71. Shimono A., Zhou H., Shen H., Hirota M., Ohtsuka T., Tang Y., 2010. Patterns of plant diversity at high altitudes on the Qinghai-Tibetan Plateau. Journal of Plant Ecology 3(1): 1-7.
72. Silva JLS., Cruz-Neto O., Tabarelli M., Albuquerque UP., Lopes AV., 2022. Climate change will likely threaten areas of suitable habitats for the most relevant medicinal plants native to the Caatinga dry forest. Ethnobiology and Conservation.
73. Sinha S., Badola HK., Chhetri B., Gaira KS., Lepcha J., Dhyani PP., 2018. Effect of altitude and climate in shaping the forest compositions of Singalila National Park in Khangchendzonga Landscape, Eastern Himalaya, India. Journal of Asia-Pacific Biodiversity. 11(2): 267-275.
74. Song X., Nakamura A., Sun Z., Tang Y., Cao M., 2016. Elevational Distribution of Adult Trees and Seedlings in a Tropical Montane Transect, Southwest China. Mountain Research and Development 36(3): 342-354.
75. Tadesse G., Zavaleta E., Shennan C., FitzSimmons M., 2014. Policy and demographic factors shape deforestation patterns and socio-ecological processes in southwest Ethiopian coffee agroecosystems. Applied Geography 54: 149-159.
76. Teshome M., Asfaw Z., Dalle G., 2020. Effect of environmental gradients on diversity and plant community distribution in remnant dry Afromontane forest of Mount Duro, Nagelle Arsi, Ethiopia. Biodiversity Research and Conservation 58(1): 21-31.

77. Tsegaye B., 1997. The significance of biodiversity for sustaining agricultural production and role of women in the traditional sector: the Ethiopian experience. Agriculture, Ecosystems and Environment 62: 215-227.
78. Uhlig SK., 1988. Mountain forests and the upper tree limit on the southeastern plateau of Ethiopia. Mountain research and development 8: 277-234.
79. Wani ZA., Khan S., Bhat JA., Malik AH., Alyas T., Pant S., Siddiqui S., Moustafa M., Ahmad AE., 2022. Pattern of β-Diversity and Plant Species Richness along Vertical Gradient in Northwest Himalaya, India. Biology 11: 1064.
80. World Bank., 2001. African Development Indicators. Washington.
81. Yami M., Mekuria W., 2022. Challenges in the Governance of Community-Managed Forests in Ethiopia: Review. Sustainability 14(3): 1478.
82. Lemenih M., Kassa H., 2014. Re-Greening Ethiopia: History, Challenges and Lessons. Forests 5: 1896-1909.
83. Yang J., El-Kassaby YA., Guan W., 2020. The effect of slope aspect on vegetation attributes in a mountainous dry valley, Southwest China. Sci Rep 10(1): 16465.
84. Yeboah SO., Amponsah IK., Kaba JS., Abunyewa AA., 2022. Abundance, richness and use of medicinal plants under different land uses in the Guinea Savanna zone of Northern Ghana. All Earth 34(1): 202-214.
85. Yirga F., Marie M., Kassa S., Haile M., 2019. Impact of altitude and anthropogenic disturbance on plant species composition, diversity, and structure at the Wof-Washa highlands of Ethiopia. Heliyon 5(8): e02284.
86. Young NE., Evangelista PH., Mengitsu T., Leisz S., 2020. Twenty-three years of forest cover change in protected areas under different governance strategies: a case study from Ethiopia’s southern highlands. Land Use Policy 91: 104426.
87. Zeleke G., Hurni H., 2001. Implications of land use and land cover dynamics for mountain resource degradation in the northwestern Ethiopian highlands. Mountain Research and Development 21(2): 184-191.
88. Zhang W., Huang D., Wang R., Liu J., Du N., 2016. Altitudinal Patterns of Species Diversity and Phylogenetic Diversity across Temperate Mountain Forests of Northern China. PLoS ONE 11(7): e0159995.
89. Zhao R., Xu S., Song P., Zhou X., Zhang Y., Yuan Y., 2022. Distribution patterns of medicinal plant diversity and their conservation priorities in the Qinghai-Tibet Plateau. J Biodiv Sci 30(4): 21385.
90. Zhu J., Lu D., Zhang W., 2014. Effects of gaps on regeneration of woody plants: a meta-analysis. Journal of Forestry Research 25: 501-510.