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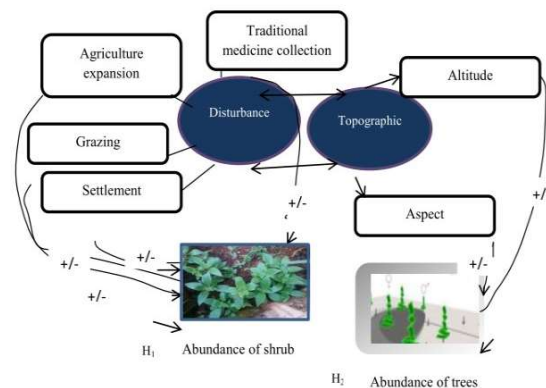
Figure 1: Hypotheses to predict plant species abundance in relation to multiple factors (disturbance and topography) in mountain Damota Wolaita, Ethiopia.

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).
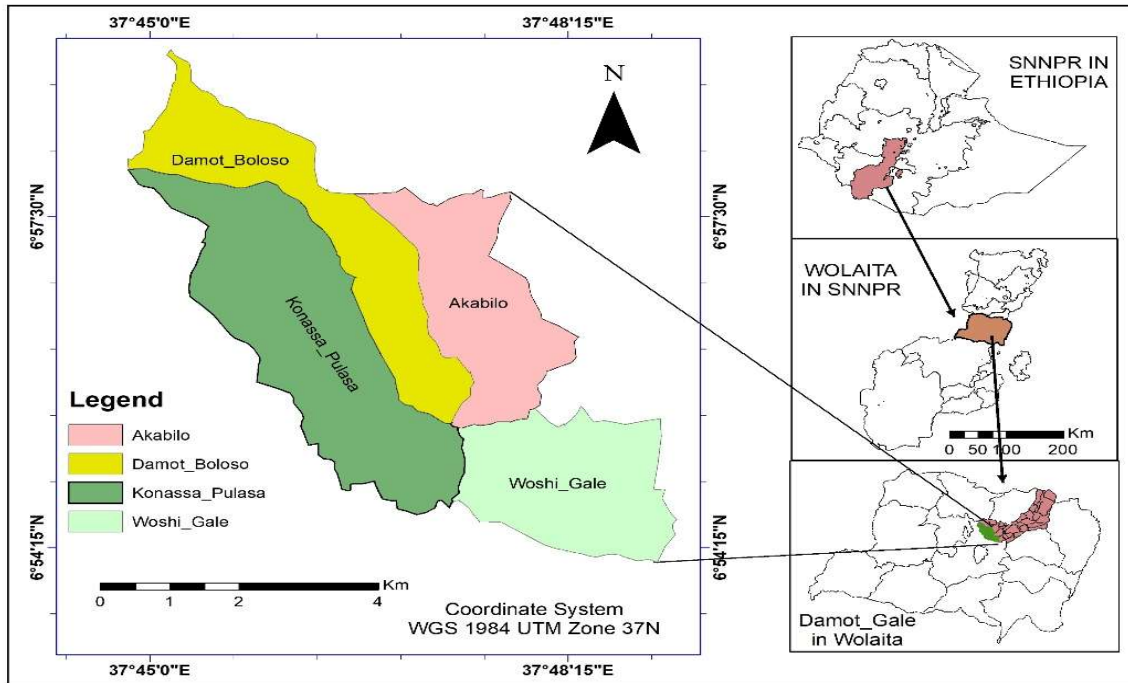
Figure 2: Study area map.

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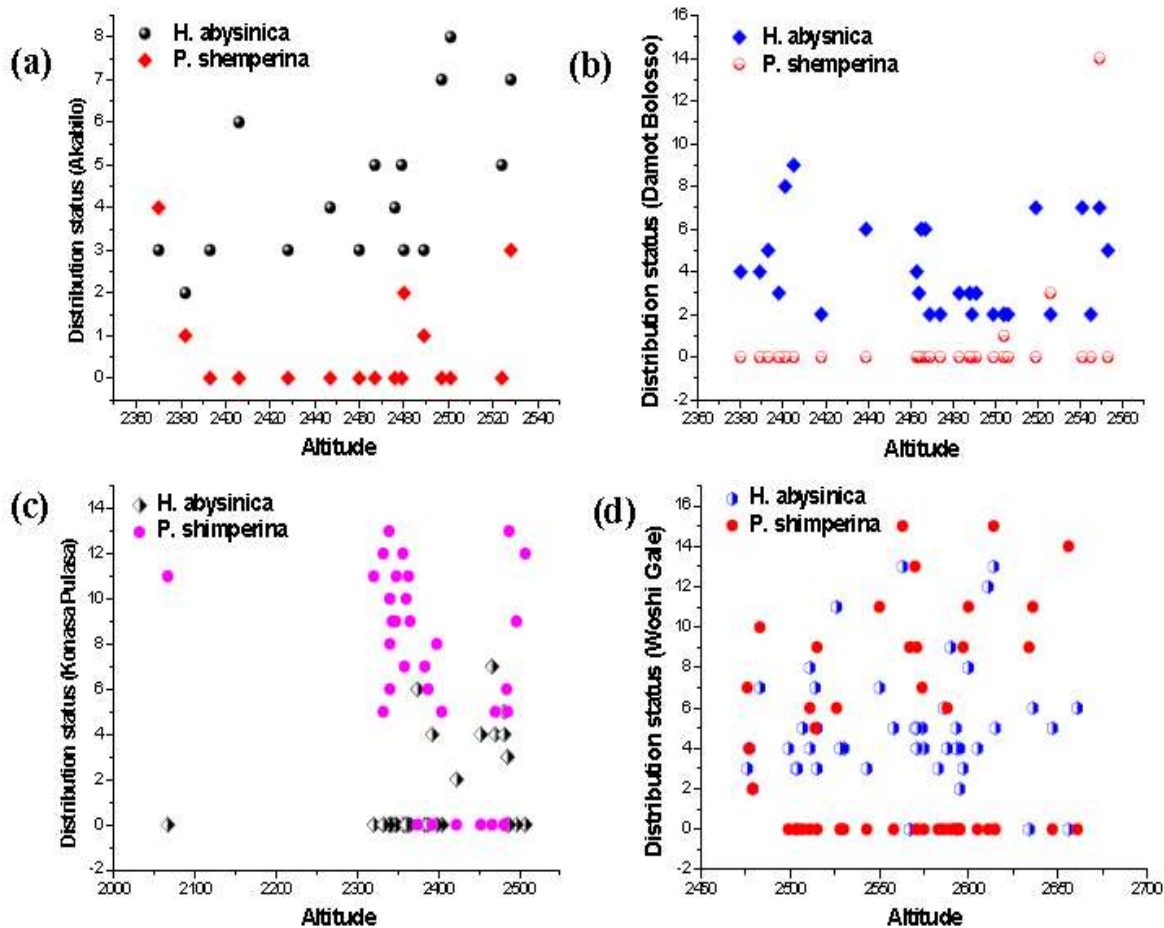
Figure 3: (a) Distribution patterns of individuals at Akabilo, (b) Damot Bolosso, (c) Konasa Pulasa, and (d) Woshi Gale districts of mountain Damota.

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. schemperina* Ab
H. abyssinica alt	1			
H. abyssinica Ab	-0.0693	1		
P. schemperina alt	-0.4271	-0.0128	1	
P. schemperina 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).
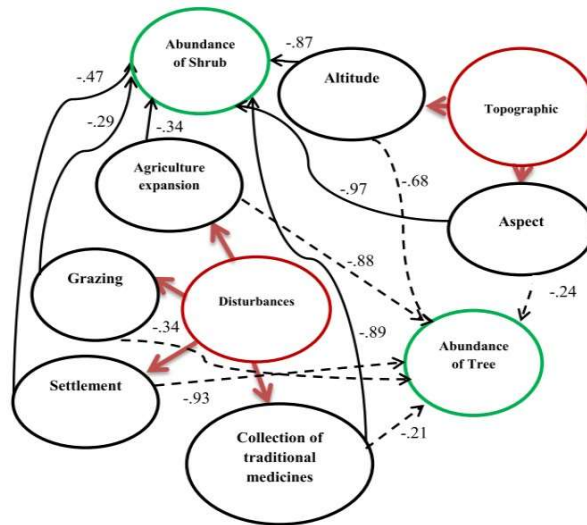
Figure 4: Structural Equation Modeling (SEM) revealing factors affecting the abundance and distribution of the species.

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, $\chi^2 = 2.61$, 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).
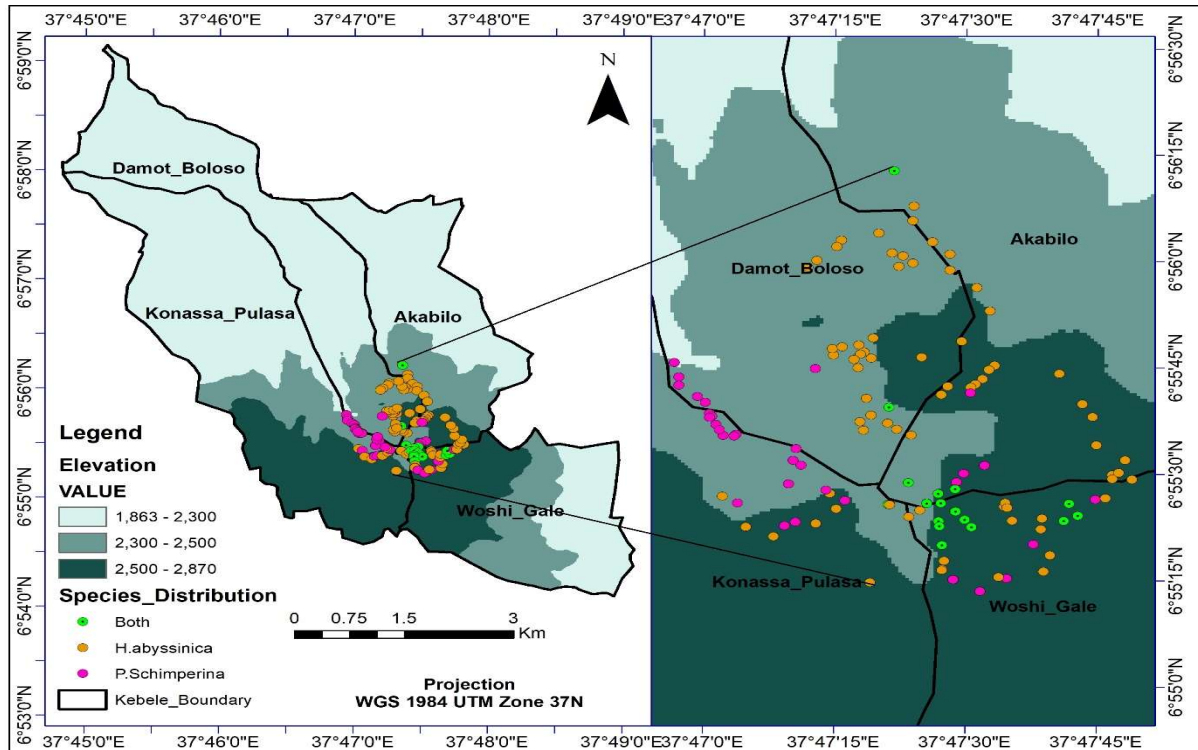
Figure 5: **Distribution patterns of *H. abyssinica* and *P. schemperina* in the study area.**

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.
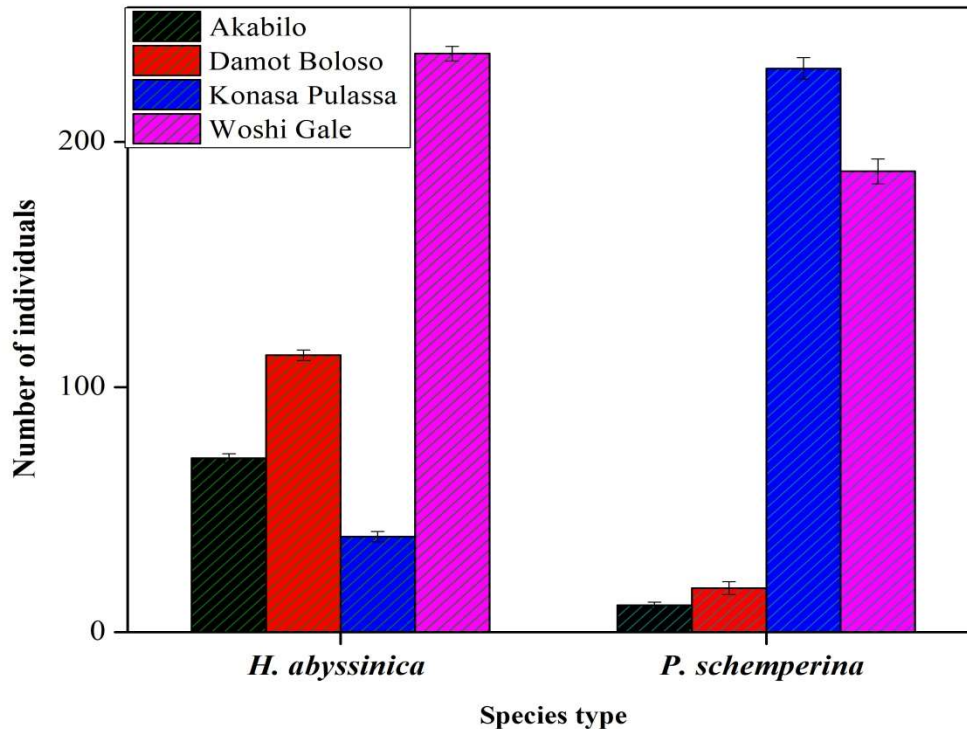
Figure 6: Species distribution at four specific study sites.

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.

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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.

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