



Landscape structure of the Gunza and Simbuwa river valleys (Southern macroslope of the Great Himalayan Range)

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ABSTRACT

This study analyzes the landscape structure of the Ghunsa and Simbuwa River valleys, which drain the southern macroslope of the Greater Himalayan Range. Landscape taxa of different ranks and the primary factors driving landscape formation were identified. The landscape framework of these valleys is represented by 11 higher-rank landscape taxa. Their vertical differentiation occurred under the influence of a significant altitudinal gradient, reaching 7 000 m over a distance of only 60 km. Consequently, a diverse spectrum of landscape taxa has formed, representing most of the natural zones found across East Asia. Analysis of the spatial distribution of soil types and plant formations allowed us to identify 20 lower-rank landscape units. Ecosystems below an elevation of 2 600 m have been significantly transformed by anthropogenic impacts. Evergreen and semi-deciduous forests have largely been replaced by agricultural crops and cultivated plant communities. In contrast, landscapes above 2 600 m are well preserved in their natural state.

Keywords: Great Himalayan Range, Mount Kanchenjunga, Simbuwa and Gunza rivers, altitudinal zonation, landscape taxa, landscape structure

РЕЗЮМЕ

Белянин П.С. Ландшафтная структура долин рек Гунза и Симбува (южный макросклон Большого Гималайского хребта). Проанализирована ландшафтная структура долин рек Гунза и Симбува, дренирующих южный макросклон Главного Гималайского хребта. Выявлены разноранговые ландшафтные таксоны и основные факторы их формирования. Установлено, что ландшафтный каркас долин рек Гунза и Симбува представлен 11 ландшафтными таксонами. Их вертикальная дифференциация произошла под влиянием гипсометрического фактора, достигающего высоты 7 000 м, на протяжении всего 60 км. В результате, сформировался разнообразный спектр ландшафтных таксонов, представляющих большинство природных зон Восточной Азии. Анализ пространственного распределения типов почв и растительных формаций позволил выделить 20 более мелких ландшафтов. Экосистемы ниже изогипсы 2 600 м существенно трансформированы в результате антропогенного воздействия. На месте вечнозелёных и полудецидуозных лесов преобладают растительные сообщества культурных растений. Ландшафты выше 2 600 м хорошо сохранили свой естественный облик.

Ключевые слова: Большой Гималайский хребет, гора Канченджанга, реки Симбува и Гунза, высотная зональность, ландшафтные таксоны, структура ландшафта

The latitudinal gradient is one of the leading factors determining the geographical distribution and differentiation of modern landscapes. It causes a decrease in biodiversity from the tropics to the poles on land and in the sea (Gaston 2000, Hillebrand 2004), as well as changes in the properties of almost all ecosystem components. Similar processes occur in mountain regions. Although the elevational gradient does not exert the same global influence on ecosystems as its latitudinal counterpart, by driving the vertical differentiation of climatic conditions, it contributes to the formation of a striking diversity of natural complexes, which is most clearly manifested on the slopes of high mountains (Gentry 1988). The most common models of altitudinal distribution predict either a linear decrease in biodiversity with increasing altitude or a

hump-shaped pattern where species richness peaks at mid-altitudes (Grytnes & Vetaas 2002).

The main factor driving altitudinal zonation is the decrease in surface air temperature with altitude (Stanyukovich 1973). The vertical temperature gradient is much more intense than the horizontal one; consequently, the altitudinal spectrum of mountain landscapes within a single climatic zone is significantly more diverse than that of lowland landscapes (Odum 1971). Although solar radiation increases by approximately 10% for every 1 000 m of elevation, longwave radiation from the Earth's surface decreases significantly faster with altitude, driving the drop in ambient air temperature. As a rule of thumb, every 100 m of ascent in the mountains is bioclimatically equivalent to moving 1° of latitude poleward. Thus, the climate in the

equatorial zone at an altitude of 1 000 m a.s.l. is highly similar to the climate near sea level at 10° latitude from the equator (Sokolova 2016).

Vegetation changes in accordance with altitude, forming altitudinal belts that are distributed in a strict zonal order in mountains. The vegetation in these belts has analogues in latitudinal zones with similar climatic conditions. For example, whereas the belt of the northernmost evergreen laurel-beech forests near the equator is found at an altitude of 3 000–3 500 m a.s.l., on Kyushu Island at approximately 37°N it descends to sea level (Ohsawa 1993). The altitudinal gradient also determines the differentiation of micro- and mesorelief forms and soils, thereby governing the nature and intensity of exogenous processes at different altitudes. The most complete vertical spectrum of landscapes is characteristic of high mountains in equatorial and tropical latitudes. A single vertical profile of such mountains can exhibit landscape changes equivalent to a shift from the equator to Arctic latitudes (Abdulkasimov et al. 2015).

One such mountain system is the Greater Himalayan Range, which hosts 10 of the 14 eight-thousander peaks on Earth. The Himalayas are the youngest and highest mountains in the world, still undergoing uplift driven by the interaction of the Indian and Eurasian continental lithospheric plates (Molnar 1986). The uplift rate of the Himalayas reaches 10 mm/year, while slope erosion ranges from 2 to 12 mm/year (Burbank et al. 1996). The world's largest altitudinal gradient (8 848 m, Mount Everest) has led to the formation, on the southern macroslope of the Himalayas, of climatic zones corresponding to a monsoon tropical climate at the foothills and an Arctic climate at the main watershed. As a result, ecosystems representing many of the Earth's natural zones have developed on the southern macroslope of the Himalayas (Paudel 2013). Nowhere else in the world are such heterogeneous landscapes found on a single macroslope. Moreover, the southern macroslope of the Eastern Himalayas, owing to the shortest distance (~80 km) from the main watershed to the Indian plains (absolute elevation 70–100 m), exhibits the greatest altitudinal gradient in the Himalayas (Schaller 1977). This leads to an even more rapid change in the natural environment with altitude.

The history of ecosystem studies in the Nepalese Himalayas is considerably shorter than that in the Indian Himalayas, as Nepal remained largely closed to foreigners until the mid-20th century. Consequently, data on the structure, functioning, and interrelationships of the ecosystems of the Great Himalayan Range remain incomplete. Analysis of the spatial differentiation patterns of landscapes on the southern macroslope of the Great Himalayan Range allows us to identify the most complete altitudinal spectrum of landscapes, to establish and analyse their relationships with geosystems at higher latitudes that operate under similar climatic conditions, and to determine the functional characteristics of mountain ecosystems in the subtropical zone.

The aim of this study is to analyse the spatial differentiation of landscape taxa in the Gunza and Simbuwa River valleys, to determine their structure, and to identify the main landscape-forming factors.

MATERIAL AND METHODS

Study area

The study area encompasses the valleys of the Ghunsa and Simbuwa rivers, which drain the southern macroslope of the Greater Himalayan Range and flow into the Tamor River. The valleys are located between approximately 27°32'00"–27°50'53"N and 87°48'07"–88°11'22"E. This region lies in the northeasternmost corner of Nepal, bordered by the Kanchenjunga Biosphere Reserve (Sikkim, India) to the east, Sankhuwasabha District (Nepal) to the west, the Qomolangma Nature Preserve (Tibet, China) to the north, and Taplejung District (Nepal) to the south.

The drainage basin of the Ghunsa River covers 774 km², while that of the Simbuwa River covers 304 km² (Fig. 1). Topographically, the valleys range from 1 550 m a.s.l. along the bank of the Ghunsa River at Sekathum to the third-highest peak on Earth, Mount Kanchenjunga (8 586 m a.s.l.). Three other mountain peaks above 8 000 m a.s.l. – Yalung Kang (8 505 m a.s.l.), Kanchenjunga South (8 476 m a.s.l.), and Yalung Kang West (8 077 m a.s.l.) – are also located within these valleys (Chaudhary 1998).

This area comprises the upper catchments of the Kanchenjunga Conservation Area, a global biodiversity hotspot (Mittermeier et al. 2004). The region represents a high-mountain physiographic zone, with approximately 41.2 % of its area covered by bare rock, 22.8 % by snow and glaciers, 16.1 % by forests, 10.0 % by shrubs, 9.3 % by pasture land, 0.5 % by agricultural land, and 0.1 % by lakes and landslides (LRMP 1978). The valleys of the Ghunsa and Simbuwa rivers are composed mainly of metamorphic rocks, with a predominance of biotite quartz-feldspar gneisses (Goscombe et al. 2006). Phytogeographically, the region is located at the junction of the East Asian and Ancient Mediterranean subkingdoms of the Holarctic Kingdom (Kamelin 2012), within the East Himalayan province, whose flora is one of the youngest in Asia (Takhtajan 1986).

Climatic settings

Due to their significant altitudinal gradient, the Gunza and Simbuwa river valleys span altitudinal zones corresponding in climatic conditions to the arctic, subarctic, cool-temperate, temperate, warm-temperate, and subtropical climate zones (Ohsawa et al. 1986).

The main climate-forming factor is the summer Indian monsoon, which accounts for significant annual precipitation (1 500–3 000 mm). About 80 % of this precipitation occurs during the period from May to October (Vetaas 2000). The slopes at 1 500–2 500 m a.s.l. receive the greatest amount of precipitation (Ives & Messerli 1989). Seasonal snow cover forms above 3 000 m a.s.l. The snow line on the northern slopes lies at 4 500–4 800 m a.s.l., and on the southern slopes at an altitude of 5 500 m a.s.l. Modern valley glaciation is developed above 4 200 m a.s.l. (Asahi & Watanabe 2000).

Field studies

During the first field survey, from 23.10. to 03.11.2015, the trekking route followed the Ghunsa River valley to the Pangpema shelters (5 140 m a.s.l.). During the second expedition, from 09.10. to 02.11.2024, the Ghunsa River



valley was revisited, along with the upper section of the valley of its left tributary, which is covered by the Jannu Glacier. The route then crossed the Sele Pass to reach the Simbuwa River valley. Fieldwork extended from the river mouths in the subtropical zone (1 550 m a.s.l.) to an altitude of 5 200 m a.s.l. in the area of modern glaciation.

To identify landscapes along the field routes, descriptions of the main landscape components were conducted at observation points established in representative valley sections across a variety of bioclimatic zones. At each sampling plot, both physical and biological characteristics

were recorded. Physical characteristics included location (measured using a Global Positioning System [GPS] receiver), altitude (determined via digital topographic maps), slope (measured using a digital clinometer), aspect (determined with a compass), and a brief description of soil conditions and the composition of underlying loose sediments. Biological characteristics included a brief description of the dominant plants within a radius of 10–20 m, as well as the types of anthropogenic impact.

Following the fieldwork, Landsat-8 satellite images and topographic maps of the Ghunsa and Simbuwa river

valleys were analyzed to evaluate the natural conditions and properties of the landscape components. To identify landscapes and determine dominant species, we utilized vegetation descriptions by Ohsawa (1977) and the plant checklist by Tamang (2013), and other which includes data on functional groups, life forms, and altitudinal distribution. The boundaries of the altitudinal zones were delineated based on the distribution scheme of principal species along altitudinal and moisture gradients in the Ghunsa and Simbuwa river basins, developed by Ohsawa (Ohsawa et al. 1986). Additionally, published data on late Pleistocene-Holocene and modern glaciation dynamics in the Ghunsa and Simbuwa valleys were incorporated (Asahi & Watanabe 2000).

Landscape mapping

For the identification of higher-rank landscape taxa, we utilized data on terrain morphometry (slope and aspect), geological structure (rock types), and substrate lithology. In identifying lower-rank landscape taxa, we employed vegetation and soil characteristics according to Nikolaev's classification (Nikolaev 1979). Due to the local scale of the study, the identified landscape taxa were classified as morphological units of the landscape. The landscape map was created using ArcGIS Desktop (ArcMap version 10.5) at a scale of 1:200 000. To calculate the proportions of the landscape units, they were combined into two groups: lower and higher ranks. Their shares were calculated based on the ratio of the area of each taxon in each group to the total area of the Ghunsa and Simbuwa River drainage basins.

RESULTS AND DISCUSSION

The landscape research results demonstrate that the contemporary structure and differentiation of landscapes in the Ghunsa and Simbuwa river valleys are determined by the interaction of multiple factors, most notably tectonic and hypsometric features. As the Indian continental lithospheric plate converges beneath the Eurasian plate, the resulting uplift of metamorphic rocks formed the bedrock foundation of modern landscapes. The subsequent development of nival, periglacial, erosional, and landslide processes led to the formation of higher-rank landscape taxa (Table 1), which comprise slopes of varying steepness, glaciers of diverse morphologies, moraines of different ages, and floodplain terraces. The landscape structure is dominated by steep and very steep slopes (51.5 %), hanging glaciers (15.6 %), and moderately steep slopes (10.8 %). Valley glaciers covered with debris (boulders, gravel, and sand) account for 9.1 %, while debris-free valley glaciers make up 6.6 %. Glacial moraines formed during the Holocene (5.0 %) and the Late Pleistocene (Marine Isotope Stages [MIS] 4–2) (4.5 %) play a secondary role, being confined primarily to valley bottoms (Fig. 3).

Elevation gradient determines the formation and vertical differentiation of lower-rank landscape taxa. Although the Ghunsa and Simbuwa river valleys are situated within the subtropical zone, their massive altitudinal span (~7 000 m) results in the dominance of ecosystems characteristic of subarctic, arctic, and temperate climates. High-mountain desert landscapes are predominant, accounting for 74.3 %

of the area. Subdominant types include alpine meadows (6.3 %), closed spruce forests (6.7 %), and stunted juniper forests (5.4 %). Other landscape types are represented by herbaceous-shrub communities dominated by *Rhododendron wightii* (2.7 %) and *Dasiphora fruticosa* (2.2 %), as well as closed oak forests (2.0 %), alpine meadows with clumps of creeping junipers (2.0 %), communities of low-growing shrubs and herbs (1.5 %), and meadow communities on pastures at various elevations (2.2 %). With increasing altitude, the surface air temperature decreases, and the vegetation becomes simpler and more cold-resistant. This shift is also facilitated by a decrease in precipitation due to the rain shadow effect in the upper parts of the valleys around the Kanchenjunga peak. Moisture-laden winds lose up to 95 % of their moisture on the southern slopes. This phenomenon creates a significant, arid rain shadow effect on the northern side, with precipitation levels dictated by elevation and windward positioning (Dhar & Nandargi 2000).

Due to the warmer climate of the slopes in the lower reaches of the Ghunsa and Simbuwa rivers, at altitudes of 1 500–2 600 m a.s.l. (corresponding to the climatic characteristics of the subtropical and warm-temperate zones), the most floristically rich, multi-layered, and high-canopy forests have formed. In this same zone, at 2 200 m a.s.l., the Ghunsa Valley exhibits the highest alpha and gamma vascular plant diversity (Tamang 2013).

The onset of frost at approximately 1 700 m a.s.l. and the subsequent decrease in surface air temperature at higher elevations lead to the dominance of semi-deciduous and evergreen forests in the 1 500–1 800 m a.s.l. altitudinal zone. Such vegetation is a typical component of subtropical geosystems. Deciduous and semi-deciduous forests with an understory of evergreen rhododendrons, characteristic of warm-temperate geosystems, predominate in the 1 800–3 600 m a.s.l. zone. They are replaced by deciduous and coniferous forests with shrubs, typical of the cool-temperate zone, between 3 600 and 3 800 m a.s.l. In this transition zone, at an altitude of ~3 800 m a.s.l., plant biodiversity reaches its minimum. Overall, total vascular plant species richness in the Ghunsa Valley exhibits a significant monotonic decrease along the elevational gradient (Tamang 2013) (Fig. 4). Landscapes of alpine meadows and shrubs, common in the subarctic zone, predominate at 3 800–4 600 m a.s.l. Above 5 000 m a.s.l. on North-facing slopes and 5 500 m a.s.l. on South-facing slopes, vegetation is entirely absent.

The key drivers of horizontal landscape differentiation in the valleys are aspect and morphometric attributes. Changes in slope aspect and steepness, which govern the redistribution of heat, moisture, and soil nutrients, lead to the formation of plant communities with distinct compositions at identical elevations.

A warm, humid climate and fertile soils have created the most favorable conditions for agriculture and human settlement at altitudes below 2 600 m a.s.l. Consequently, the multi-layered, high-canopy evergreen and semi-deciduous forests in this zone have been heavily deforested. The combination of forest clearance and specific environmental variables – such as fluctuations in temperature, moisture, soil pH, nutrient availability, soil organic matter, and changes

Table 1. Spatial distribution of landscapes in the valleys of the Ghunza and Simbuwa rivers.

Altitude range, m a.s.l.	2	3	4	5	6	7	8	Dominant plants species
	Corresponding climatic zones (after Ohsawa 1977)	Names of higher-rank landscape taxa and their designations in Fig. 2	Rock type	Substrate lithology (overlying geological formations)	Names of smaller-rank landscape taxa and their designations in Fig. 2	Soil type		
5 600–4 200	Arctic	Valley glaciers with inclusions of boulders, gravel, and sand (X)	Gneiss and schists	There is no substrate	-	Soils are poorly developed	No vegetation	
>5 000	Frosty climate	Steep and very steep slopes (I); Moderately steep slopes (II); Gentle slopes (III)	Gneiss and schists	Rubble, boulders, weathered boulders, gravel, and coarse-grained sand	High-mountain deserts (1)	Rocky skeletal soils	<i>Saussurea</i> spp., <i>Minuartia</i> spp. and <i>Arenaria bryophylla</i>	
>5 200	Arctic	Valley glaciers composed of pure ice (IX)	Gneiss and schists	There is no substrate	-	Soils are poorly developed	No vegetation	
>5 200	Arctic	Hanging glaciers composed of clear ice (XI)	Gneiss and schists	There is no substrate	-	Soils are poorly developed	No vegetation	
5 100–4 300	Arctic, Subarctic	Steep and very steep slopes (I); Moderately steep slopes (II); Gentle slopes (III); Glacial moraines formed in the Holocene (MIS 1) (VI); Glacial moraines formed in the Late Pleistocene (MIS 2) (VII)	Gneiss, and shales	Rubble, boulders, weathered boulders, gravel, and coarse-grained sand	Communities of low-growing shrubs and herbs (2)	Rocky skeletal soils	<i>Berberis</i> sp., <i>Ephedra gerardiana</i> , <i>Juniperus indica</i> , <i>Pleuropernum</i> , <i>Potentilla fruticosa</i> , <i>Rheum acuminatum</i> , <i>Rhodiola bipleuroides</i> , <i>Rhododendron anthopogon</i> , <i>Rh. leptolium</i> , <i>Rh. nivale</i> , <i>Rh. pendulum</i> , <i>Rh. setosum</i>	
5 100–4 200	Arctic, Subarctic	Steep and very steep slopes (I); Moderately steep slopes (II); Gentle slopes (III); Glacial moraines formed in the Holocene (MIS 1) (VI); Glacial moraines formed in the Late Pleistocene (MIS 2) (VII)	Gneiss and schists	Rubble, boulders, weathered boulders, gravel, and coarse-grained sand	Alpine meadows (3)	Rocky skeletal soils	<i>Arenaria</i> sp., <i>Carex</i> sp., <i>Cassiope fastigiata</i> , <i>Corticea depressa</i> , <i>Cremnathodium</i> sp., <i>Gentiana algida</i> , <i>Geranium donianum</i> , <i>Leontopodium monocephalum</i> , <i>Mecanopsis horridula</i> , <i>Potentilla</i> sp., <i>Primula</i> sp., <i>Saussurea simpsoniana</i> , <i>S. obtusilata</i> , <i>Saxifraga hemisphaerica</i> , <i>S. punctulata</i> , <i>Swertia hookeri</i> , <i>Thermopsis inflata</i>	
5 000–3 500	Cool-temperate, Subarctic, Arctic	Steep and very steep slopes (I); Moderately steep slopes (II); gentle slopes (III);	Gneiss and schists	Rubble, and boulders	Meadow communities on high-mountain pastures (18)	Rocky skeletal soils	<i>Carex</i> sp., <i>Corticea depressa</i> , <i>Geranium donianum</i>	
4 800–3 700	Arctic, Subarctic, Cool-temperate	Steep and very steep slopes (I); Moderately steep slopes (II); gentle slopes (III); Glacial moraines formed in the Holocene (MIS 1) (VI); Glacial moraines formed in the Late Pleistocene (MIS 2) (VII)	Gneiss and schists	Rubble, boulders, weathered boulders, gravel, and coarse-grained sand	Alpine meadows with clumps of creeping junipers (4)	Rocky skeletal soils	<i>Arisaema</i> sp., <i>Bistorta vivipara</i> , <i>Calamagrostis filiformis</i> , <i>Carex alpina</i> , <i>Juniperus indica</i> , <i>J. squamata</i> , <i>Kobresia nepalensis</i> , <i>Poa alpina</i> , <i>Rhodiola bipleuroides</i> , <i>Pleuropernum</i> , <i>Potentilla</i> sp., <i>Primula</i> sp.	
4 750–3 800	Arctic, Subarctic, Cool-temperate	Steep and very steep slopes (I); Moderately steep slopes (II); gentle slopes (III); Glacial moraines formed in the Holocene (MIS 1) (VI); Glacial moraines formed in the Late Pleistocene (MIS 2) (VII)	Gneiss, and shales	Rubble, boulders, weathered boulders, gravel, and coarse-grained sand	Herbaceous-shrub thickets with dominated <i>Potentilla fruticosa</i> (5)	Rocky skeletal soils	<i>Arenaria</i> sp., <i>Berberis</i> sp., <i>Cassiope fastigiata</i> , <i>Cremnathodium</i> sp., <i>Ephedra gerardiana</i> , <i>Gentiana algida</i> , <i>Leontopodium monocephalum</i> , <i>Mecanopsis horridula</i> , <i>Potentilla fruticosa</i> , <i>Rosa</i> sp., <i>Saussurea simpsoniana</i> , <i>S. obtusilata</i> , <i>Saxifraga hemisphaerica</i> , <i>S. punctulata</i> , <i>Spiraea</i> sp., <i>Swertia hookeri</i> , <i>Thermopsis inflata</i>	

Table 1. Continued.

1	2	3	4	5	6	7	8
4 200–3 900	Cool-temperate, Temperate, Warm-temperate, Subtropical	River channels and Floodplain terraces (IV)	Gneiss and schists	Boulders, pebbles, and sands	For the explanation, see the names of smaller-rank landscape taxa in column 6 (corresponding to designations Nos. 4, 5, and 7–18)	Alluvial skeletal soils	For the explanation, see the description of dominant plant species in column 7 (corresponding to smaller-rank landscape taxa Nos. 4, 5, and 7–18)
4 200–3 800	Subarctic	Steep and very steep slopes (I); Moderately steep slopes (II); gentle slopes (III); Glacial moraines formed in the Holocene (MIS 1) (VI); Glacial moraines formed in the Late Pleistocene (MIS 2) (VII)	Gneiss, and shales	Rubble, boulders, weathered boulders, gravel, and coarse-grained sand	Herbaceous-shrub thickets with dominated <i>Rhododendron nigritii</i> (6)	Rocky skeletal weakly humified soils	<i>Betula utilis</i> , <i>Juniperus squamata</i> , <i>Rhododendron campanulatum</i> , <i>Rh. wightii</i>
4 100–2 800	Temperate, Warm-temperate, Temperate, Subarctic	Moderately steep slopes (II); Gentle slopes (III)	Gneiss and schists	Rubble, boulders, and sands	Plantations of moderately-thermophilic crops (20)	Transformed brown forest soils and skeletal brown forest soils	<i>Amaranthus</i> spp., <i>Brassica oleracea</i> , <i>Daucus carota</i> , <i>Elaeagnus corucana</i> , <i>Fragopyrum esculentum</i> , <i>F. tataricum</i> , <i>Hordeum vulgare</i> , <i>Oryza sativa</i> , <i>Panicum miliaceum</i> , <i>Setaria italica</i> , <i>Solanum melongena</i> , <i>S. tuberosum</i>
3 900–3 000	Temperate, Cool-temperate	Steep and very steep slopes (I); Moderately steep slopes (II); gentle slopes (III); Glacial moraines formed in the Holocene (MIS 1) (VI); Glacial moraines formed in the Late Pleistocene (MIS 2) (VII)	Gneiss, and shales	Rubble, boulders, weathered boulders, gravel, and coarse-grained sand	Sparse forests (8)	Rocky skeletal and brown forest soils	<i>Abies spectabilis</i> , <i>Acer caudatum</i> , <i>A. pectinatum</i> , <i>Betula utilis</i> , <i>Juniperus recurva</i> , <i>Larix griffithii</i> , <i>Rhododendron arboreum</i>
3 800–3 100	Temperate, Cool-temperate	Floodplain terraces (IV); glacial moraines formed in the Holocene (MIS 1) (VI); Glacial moraines formed in the Late Pleistocene (MIS 2) (VI); Glacial moraines formed in the Late Pleistocene (MIS 4–3) (VIII)	Gneiss, and shales	Rubble, boulders, weathered boulders, gravel, coarse-grained sand and oxidized sand	Juniper forests (10)	Rocky skeletal and brown forest soils	<i>Juniperus recurva</i> , <i>Larix griffithii</i> , <i>Rhododendron arboreum</i>
3 800–3 000	Temperate, Cool-temperate	Steep and very steep slopes (I); Moderately steep slopes (II); gentle slopes (III); Floodplain terraces (IV); Glacial moraines formed in the Late Pleistocene (MIS 4–3) (VIII)	Gneiss, and shales	Rubble, boulders, sands, weathered boulders, gravel, and oxidized sand	Closed spruce forests (11)	Rocky skeletal and brown forest soils	<i>Abies spectabilis</i> , <i>Acer campbellii</i> , <i>A. pectinatum</i> , <i>Ljonia ovalifolia</i> , <i>Mussaenda frondosa</i> , <i>Prunus</i> sp., <i>Quercus glauca</i> , <i>Q. semecarpifolia</i> , <i>Taxus malliichiana</i>
3 700–3 100	Temperate, Cool-temperate	Steep and very steep slopes (I); Moderately steep slopes (II); Gentle slopes (III); Glacial moraines formed in the Holocene (MIS 1) (VI); Glacial moraines formed in the Late Pleistocene (MIS 2) (VII)	Gneiss, and shales	Rubble, boulders, weathered boulders, gravel, and coarse-grained sand	Thickets of rhododendron shrubs (7)	Rocky skeletal and brown forest soils	<i>Acer campbellii</i> , <i>Magnolia campbellii</i> , <i>Quercus semecarpifolia</i> , <i>Rhododendron arboreum</i> , <i>Tsuga dumosa</i> ,
3 500–3 100	Temperate, Cool-temperate	Glacial moraines formed in the Holocene (MIS 1) (VI); Glacial moraines formed in the Late Pleistocene (MIS 2) (VII)	Gneiss, and shales	Rubble, boulders, weathered boulders, gravel, and coarse-grained sand	Larch forests (9)	Rocky skeletal and brown forest soils	<i>Juniperus recurva</i> , <i>Larix griffithii</i>

Table 1. Continued.

1	2	3	4	5	6	7	8
3 500–2 000	Temperate	Steep and very steep slopes (I); Moderately steep slopes (II); Gentle slopes (III); Floodplain terraces (IV)	Gneiss and schists	Rubble, boulders, sands, boulders, pebbles, and sand	Meadow communities on mid-mountain pastures (18)	Brown forest soils	<i>Bistortia vivipara</i> , <i>Calamagrostis filiformis</i> , <i>Carex alpina</i> , <i>Kobresia nepalensis</i> , <i>Poa alpina</i> , <i>Rhodiola biplexaroides</i>
3 100–2 500	Temperate	Steep and very steep slopes (I); Moderately steep slopes (II); Gentle slopes (III); Floodplain terraces (IV); Glacial moraines formed in the Late Pleistocene (MIS 4–3) (VIII)	Gneiss, and shales	Rubble, boulders, sands, weathered boulders, gravel, and oxidized sand	Closed oak forests (12)	Brown forest and alluvial soils	<i>Acer campbellii</i> , <i>Quercus semecarpifolia</i> , <i>Tsuga dumosa</i>
3 000–2 300	Temperate	Steep and very steep slopes (I); Moderately steep slopes (II); gentle slopes (III); Floodplain terraces (IV); Glacial moraines formed in the Late Pleistocene (MIS 4–3) (VIII)	Gneiss, and shales	Rubble, boulders, sands, weathered boulders, gravel, and oxidized sand	Bamboo thickets (13)	Rocky skeletal and brown forest soils	<i>Yushania maling</i>
2 800–2 300	Temperate	Steep and very steep slopes (I); Moderately steep slopes (II); gentle slopes (III); Floodplain terraces (IV)	Gneiss, and shales	Rubble, boulders, sands, boulders, pebbles, and sand	Closed deciduous polydominant forests (14)	Brown forest soils	<i>Acer campbellii</i> , <i>Lithocarpus pachyphylla</i> , <i>Sorbus cuspidata</i> , <i>Tsuga dumosa</i>
2 800–1 900	Temperate, Warm-temperate	Steep and very steep slopes (I); Moderately steep slopes (II); Gentle slopes (III); Floodplain terraces (IV)	Gneiss, and shales	Rubble, boulders, sands, boulders, pebbles, and sand	Polydominant, evergreen and deciduous broadleaf forests with pine (15)	Brown forest and alluvial soils	<i>Alnus nepalensis</i> , <i>Castanopsis hystrix</i> , <i>Pinus mulliebiana</i> , <i>Quercus lamellosa</i> , <i>Q. lineata</i>
2 800–1 500	Temperate, Warm-temperate	Moderately steep slopes (II); Gentle slopes (III)	Gneiss, and shales	Rubble, boulders, sands	Plantations of thermophilic crops (20)	Transformed brown forest soils and red soils	<i>Amaranthus</i> spp., <i>Brassica oleracea</i> , <i>Daucus carota</i> , <i>Elaeagnus coracana</i> , <i>Fragopyrum esculentum</i> , <i>F. tataricum</i> , <i>Hordeum vulgare</i> , <i>Ipomoea batatas</i> , <i>Macrotyloma uniflorum</i> , <i>Oryza sativa</i> , <i>Panicum millicecum</i> , <i>Phaseolus vulgaris</i> , <i>Setaria italica</i> , <i>Solanum melongena</i> , <i>S. tuberosum</i>
2 400–1 500	Subtropical Warm-temperate	Moderately steep slopes (II)	Gneiss and schists	Rubble, and boulders	Black cardamon plantations (19)	Red soils and brown forest soils	<i>Alnus nepalensis</i> , <i>Amonum subulatum</i> , <i>Engelhardtia</i>
2 000–1 500	Subtropical Warm-temperate	Steep and very steep slopes (I); Moderately steep slopes (II); Gentle slopes (III); Floodplain terraces (IV)	Gneiss, and shales	Rubble, boulders, sands, boulders, pebbles, and sand	Meadow communities on low-mountain pastures (18)	Red soils	Poaceae, Polygonaceae, Rosaceae and <i>Artemisia</i>
1 900–1 500	Subtropical, Warm-temperate	Steep and very steep slopes (I); Moderately steep slopes (II); Gentle slopes (III); Floodplain terraces (IV)	Gneiss, and shales	Rubble, boulders, sands, boulders, pebbles, and sand	Closed polydominant evergreen forests (16)	Red soils and brown forest soils	<i>Alnus nepalensis</i> , <i>Quercus lanata</i> subsp. <i>lanata</i>
1 900–1 500	Subtropical, Warm-temperate	Steep and very steep slopes (I); Moderately steep slopes (II); Gentle slopes (III); Floodplain terraces (IV)	Gneiss, and shales	Rubble, boulders, sands, boulders, pebbles, and sand	Closed polydominant evergreen forests (17)	Red soils and brown forest soils	<i>Alnus nepalensis</i> , <i>Castanopsis tribuloides</i> , <i>Engelhardtia spicata</i>

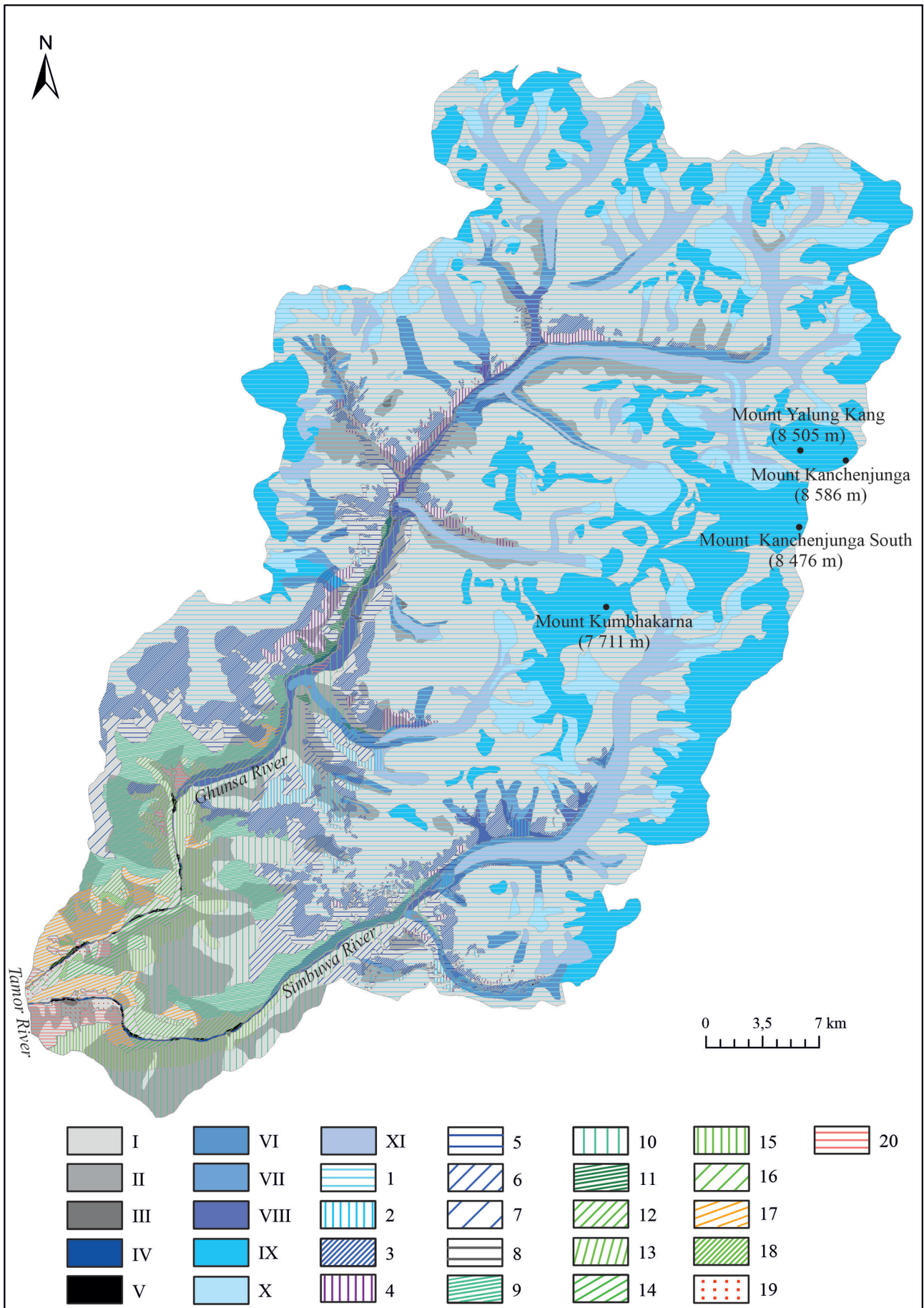


Figure 2 Map of spatial differentiation of landscape taxa in the valleys of the Ghunsa and Simbuwa rivers. For explanation see Table 1

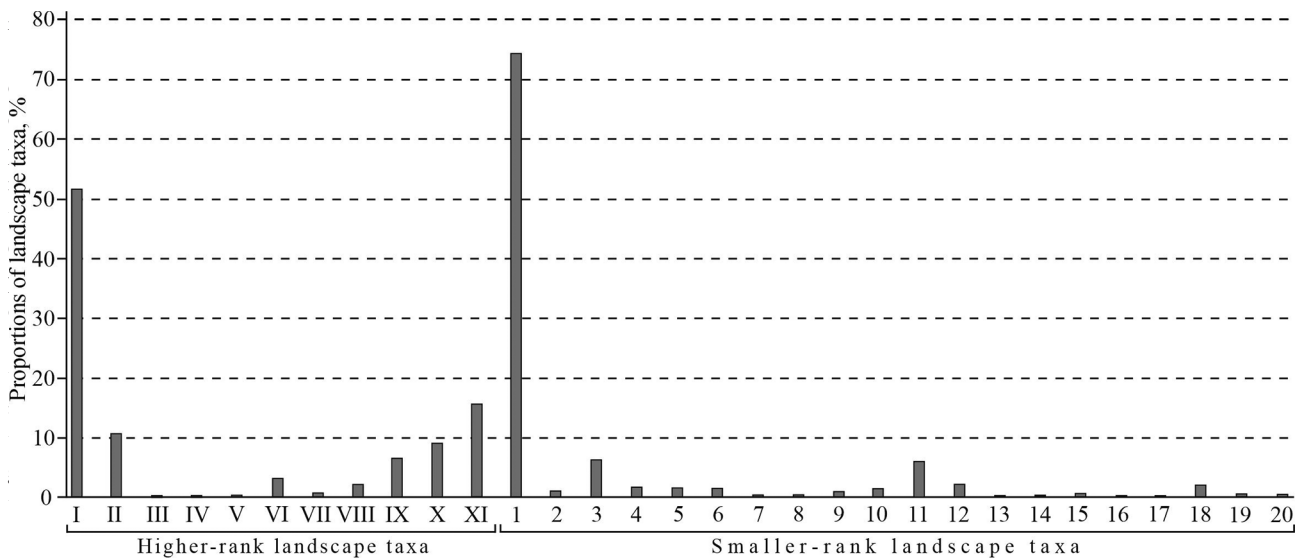


Figure 3 Percentage of landscape taxa of the Gunza and Simbuwa river valleys. For explanation, see Fig. 2

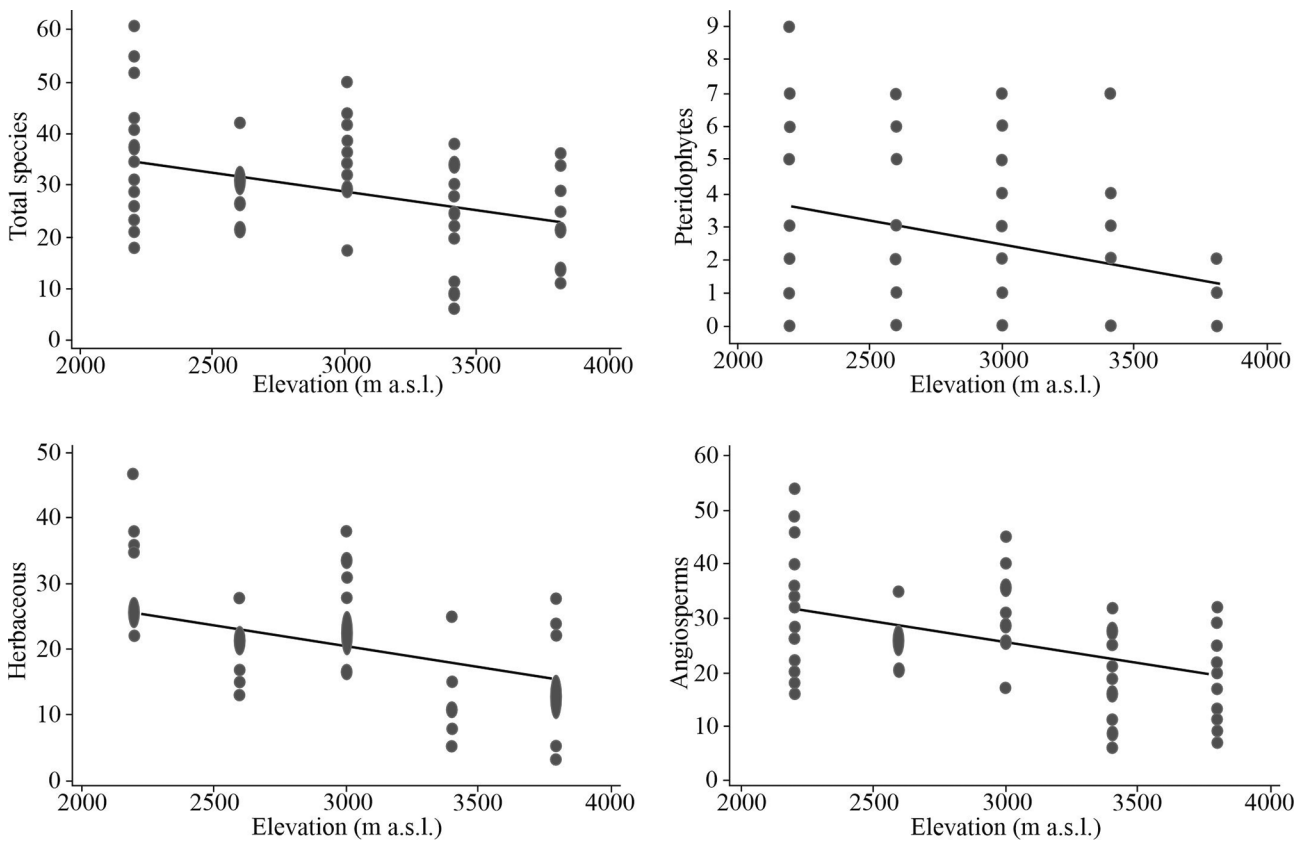


Figure 4 Relationship of total, pteridophyte, herb and angiosperm species richness with elevation in the Gunza River Basin (after Tamang 2013)

ning, pollarding tree branches for livestock feed, and grazing also have a significant negative impact on biodiversity. Another factor driving forest degradation in this altitudinal belt is the establishment of black cardamom (*Amomum subulatum*) plantations; the Taplejung District accounts for approximately 30 % of the total production in Nepal (Bhushal et al. 2020). Significant areas of the slopes in the Ghunsa and Simbuwa river valleys are also occupied by terraced rice fields, lentil (*Lens culinaris*) plantations, and vegetable crops. In addition, unpaved roads have been actively constructed

in the Ghunsa Valley in 2013 (Sherchan & Bhandari 2017), which decreased to approximately 195 animals by 2022 (Byers et al. 2024). Similar decreases were reported for adjacent valleys outside the Kanchenjunga Conservation Area (Gorlick 2022).

Another important factor of anthropogenic impact at altitudes of 3 000–3 800 m a.s.l. is deforestation – predominantly through the logging of *Abies spectabilis* and, to a lesser extent, *Tsuga dumosa* – for the construction of residential and commercial buildings. Additionally, the slow-growing

shrub *Juniperus indica*, which grows at altitudes of 3 700–5 100 m a.s.l., is threatened by overexploitation, as it serves as the primary fuelwood source (after dried yak dung) for tourist lodges in Lhonak and Ghunsa (Khangpachen). This pressure is driven by a small but steady flow of tourists in the Ghunsa and Simbuwa valleys. In the Kanchenjunga Conservation Area, tourist numbers averaged 546 per year between 2010 and 2020. The number of trekkers in autumn 2022 reached a historical high of 710 visitors, according to data from the Ghunsa police station (Byers et al. 2024).

CONCLUSIONS

An analysis of the spatial differentiation of landscape taxa in the valleys of the Ghunsa and Simbuwa rivers enables the identification of a diverse altitudinal spectrum of landscapes in the Eastern Himalayas and the determination of the main patterns and drivers of their spatial differentiation. It has been established that moderately steep and very steep slopes predominate among the higher-rank landscapes, which are represented by 11 taxa. Tectonic factors played a key role in their formation, while the final differentiation of the landscape structure occurred under the influence of nival, erosional, and landslide processes. The active accumulation of loose sediments led to the formation of gentle slopes.

Hypsometric and climatic gradients play a key role in the altitudinal differentiation and formation of lower-rank landscapes, represented by 20 taxa. A decrease in temperature and a change in humidity, synchronous with an increase in altitude, lead to the replacement of subtropical plants in the lower parts of the valleys by representatives of temperate and subarctic floras in their upper reaches. The main drivers of vegetation differentiation at identical altitudes are changes in slope aspect and steepness. Large-scale agricultural development below 2 600 m a.s.l. has led to a significant transformation of ecosystems in this zone. In contrast, landscapes at higher altitudes are well preserved in their natural state.

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