Traditional use of medicinal plants in the Chyangthapu-Phalaicha biological sub-corridor, Panchthar District, Kangchenjunga Landscape, Nepal

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1 Traditional use of medicinal plants in the Chyangthapu-Phalaicha
2 biological sub-corridor, Panchthar District, Kangchenjunga
3 Landscape, Nepal

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Abstract

Background: Chyangthapu-Phalaicha located in the northeastern Panchthar District, is a biodiversity hotspot in the Eastern Himalaya. The area is dominated by the Kirat indigenous community. The present study was conducted to document the knowledge of the ethnomedicinal uses and practices that exist in the area before the associated socio-cultural knowledge on biological diversity is lost.

Methods: Ethnomedicinal data were collected through semi-structured questionnaires. Stakeholders meetings were organized for assessing the conservation issues in the sub-corridor. The importance of medicinal plant species was assessed using quantitative indices such as informant consensus factor, relative frequency of citation, relative importance, fidelity level and Rahman's similarity index.

Results: Altogether, 140 medicinal plant species from 68 families and 127 genera were reported, which were used to treat 12 health disorders categories. The dominant families were Asteraceae and Fabaceae which contributed eight species each. Fifty-five percent of the total medicinal plant species comprised of herbs. The most frequently used plant parts were underground parts (33%) and leaf (15%). The most common remedies preparation method was extract. Oral administration was the most common therapeutic mode (60%). Maximum informant consensus factor (0.96) was calculated for gastrointestinal disorders. The highest relative frequency of citation and fidelity level was observed for *Swertia chirayita* (0.83 and 100% respectively). *Artemisia dubia* depicted the highest relative importance (91.67). A thorough review of previous literature and analysis of field data revealed new therapeutic use reports for 41 ailments associated with 52 plant species. The Rahman similarity index was high with the studies in neighbouring areas, while it was low with the geographically distant studies.

Conclusions: The ethnomedicinal study of the Chyangthapu-Phalaicha biological sub-corridor in the Kangchenjunga Landscape indicates that the area supports significant medicinal plants and associated traditional knowledge. The varied use of reported medicinal plants in the area indicates the need for their domestication, processing and phytochemical investigation, especially for those with high ethnobotanical indices.

Keywords: Ailments, East Himalaya, East Nepal, Ethnomedicine, Indigenous knowledge, Quantitative analysis

1 **Background**

2 Mountain people living in remote areas have a sound harmony with nature along with a
3 deep understanding of interacting sustainably with it [1, 2]. They developed skills, beliefs
4 and practices in order to maintain a healthy ecosystem [1]. They use a variety of plant
5 resources for livelihood security, financial income and more importantly for health care [3-
6 5]. Considering that about 25% of modern drugs are derived from plants [6-8], the
7 traditional knowledge of indigenous communities is important in the preparation of herbal
8 remedies and in the isolation of bioactive constituents, which may lead to the discovery of
9 novel drugs [9-12]. Traditional remedies are cheap, easy and sustainable options over
10 modern drugs, so the existing knowledge of indigenous people on plants and their
11 traditional uses need to be documented systematically [13, 14]. However, socio-economic
12 transformation, land-use change, overexploitation of natural resources and climate change
13 are factors contributing to the worldwide loss of biological resources and the associated
14 traditional knowledge [15-18]. In addition, the lack of interest among the younger
15 generation in traditional herbal therapies and their preference for modern medicines has
16 made the indigenous knowledge vulnerable [19].

17 More than 2,000 plant species are reported to have medicinal value in Nepal [20, 21, 22,
18 23], and 85% of the population is dependent on traditional herbal medicine for primary
19 health care [20]. Regardless of the wide use of herbal medicine, the associated traditional
20 knowledge of medicinal plant species is gradually disappearing with increasing
21 urbanization, out-migration and climate change [24, 25]. The Chyangthapu-Phalaicha
22 biological sub-corridor within the Eastern Nepal Conservation Corridor in the
23 Kangchenjunga Landscape is a human-inhabited landscape of cultural and ecological

significance [26, 27]. While this area is gradually growing towards urbanization, there is still a high incidence of poverty in the area (approximately 10% of the population) and out-migration is also very high [27]. Growing urbanization and increasing youth out-migration for better economic opportunities will have a major impact on the transfer of indigenous knowledge to younger generations resulting in the depletion of traditional knowledge. Hence, documenting the local medicinal plant species, traditional uses, and formulating guidelines for their conservation and management are important. The present study was, therefore, carried out in the Chyangthapu-Phalaicha biological sub-corridor to document the medicinal plant species and their traditional use patterns within the local community. The information generated will potentially contribute to the conservation and sustainable use of local plant resources [27, 28], along with the preservation of cultural and genetic diversity [29, 30].

Methods

Study area

The Kangchenjunga Landscape (KL) in the Eastern Himalaya is a transboundary landscape that connects adjoining areas of Nepal, India, and Bhutan [31]. This landscape is connected through seven conservation corridors (Fig. 1) and exhibits exceptionally rich biodiversity with three Important Bird Areas (IBA) and 18 Important Plant Areas (IPAs) [26, 27]. This landscape is also a part of the “Himalaya” biodiversity hotspot, one of the 36 global biodiversity hotspots accommodating diverse ecosystems, species and genetic resources of global importance [27].

1 Chyangthapu-Phalaicha biological sub-corridor is a part of the East Nepal Conservation
2 Corridor of Kangchenjunga Landscape. Located in the northeastern part of Yangawarak
3 Rural Municipality (RM), Panchthar District, Eastern Nepal (Fig. 1), the sub-corridor
4 borders with Barsey Rhododendron Sanctuary, Sikkim, India in the east, Falelung RM in
5 the south, Hilihang RM in the west, and Taplejung District in the north (Fig. 1). The altitude
6 ranges from 1600 m asl (meter above sea level) at Chyangthapu village to 4500 m asl at
7 Timbu Pokhari. The climatic condition of the area is subtropical at the lower elevations,
8 temperate in the mid-hills, and subalpine and alpine at the higher elevations.

9 The area is dominated by the indigenous Kirats (Limbu, Rai), followed by Gurungs,
10 Brahmins, Chhetris, and other caste and ethnic groups [32]. Livelihood strategies of local
11 communities cover both on-farm and off-farm activities. Agriculture is the major
12 livelihood strategy and includes mixed farming systems of crop production and animal
13 husbandry. The major cultivated crops are paddy, millet, maize, and wheat. Cash crop
14 production of large cardamom is highly significant [33]. Animal husbandry is an integral
15 part of agriculture systems in the sub-corridor. While stall-fed livestock, including cows,
16 goats, and pigs are kept at the lower elevations, yaks, and yak-crossbreeds (i.e. *Chauri*) are
17 maintained at the higher elevations with some families engaged in transhumance [34, 35].
18 Historically, the study area was administered by an indigenous land management system
19 called *Kipat* [36, 37]. This communal land ownership system used traditional governance
20 practices for conservation and sustainable management of the forest resources and the
21 pastures [36, 38]. However, since 1965, the forest areas in the study area have been
22 nationalized with the amendment of the Birta Unmulan Act followed by the Pastureland
23 Nationalisation Act a decade later [35-39].

Fig. 1 Map of study area: A. Nepal, B. Kangchenjunga Landscape (source: [31]), C. East Nepal Conservation Corridor, D. Yangawarak RM

Data collection and plant identification

Ethnobotanical data were collected between September 2016 and October 2017. Information on the medicinal plant use was gathered through semi-structured questionnaires with local healers, herders, and other knowledgeable individuals, comprising 50 participants (20 women and 30 men) whose ages ranged from 31 to 80. Before conducting the interviews, information about the Kangchenjunga Landscape was provided and a prior informed consent was sought from interviewees who granted it on condition that the collected data would be used only for academic purposes.

The questionnaires were designed to collect data on: (i) vernacular names of the plants, (ii) ailments treated by using the plant species, (iii) preparation of remedies, and (iv) therapeutic administration. Other information including the participant's name, age, occupation and the geographic locality and date of the interview were also noted.

Plant specimens were collected and identified using floras and taxonomic literature [40-48] and by consulting digital databases of the National Herbarium and Plant Laboratories (KATH) and Herbarium of the University of Tokyo (TI). The collected specimens were deposited in the Tribhuvan University Central Herbarium (TUCH). Specimens collected from the Chyangthapu-Phalaicha by other researchers, deposited at KATH and TI are also cited in Table 2 with corresponding voucher numbers. The nomenclature of the family followed APG IV [49]. TROPICOS [50] and Plant of the World Online [51] were consulted for authentication of the species name.

1 Stakeholders' meetings were organized in the district headquarter Phidim and in
2 Chyangthapu Village to discuss the conservation issues, challenges and associated socio-
3 economic conditions in the study area. The participants of these meetings were the
4 representative of the District Forest Office (now Division Forest Office), local
5 administrative divisions, youth clubs, political parties and community leaders. Based on
6 these meetings and field observation, several issues were identified, which are discussed
7 in the section 'Threats to ethnomedicinal plant species and conservation practices'.

8 **Ethnomedicinal data analysis**

9 The data were analyzed using both qualitative and quantitative approaches. The collected
10 data were generalized qualitatively to document the medicinal plant species, their life
11 forms, habitat and plant parts utilization. The non-parametric Kruskal-Wallis test was used to
12 check the significant difference between the number of plant species used and their uses in different
13 categories, the level of significance value being set at 0.5.

14 The quantitative analysis included calculation of ethnobotanical indices as follows:

15 ***Informant consensus factor (ICF)***

16 This quantitative tool is used to test the homogeneity of knowledge among participants;
17 ICF was calculated as [52]

$$18 \quad ICF = \frac{Nur - Nt}{Nur - 1}$$

19 Where Nur refers to the number of uses reported for a specific use category, and Nt refers
20 to the number of taxa used for a particular use category by all participants. Informant

1 consensus factor (ICF) values are low (near 0) when plants are selected randomly or when
2 there is no exchange of information about their use among participants, and approach one
3 (1) when there is a well-defined selection criterion in the community and/or if the
4 information is exchanged between participants [53].

5 ***Relative frequency of citation (RFC)***

6 RFC is calculated to identify the plant species most used by the local people [54]. The RFC
7 value is '0' when no one refers to the plant as being useful and '1' when all the participants
8 refer to the plant as being useful. RFC is calculated as

$$9 \quad RFC = \frac{FC}{N}$$

10 Where, 'FC' denotes the number of participants who mention the use of the species, and N
11 denotes the total number of participants.

12 ***Relative importance (RI)***

13 The technique of relative importance was developed by Bennet and Prance [55]. It
14 measures the usefulness of a plant species based on the number of pharmacological
15 properties attributed to it and the number of the body systems it affects. It is calculated as:

$$16 \quad RI = (Rel\ PH + Rel\ BS) \times \frac{100}{2}$$

17 where *PH* is the number of pharmacological properties for the given plant and *Rel PH* is
18 the relative number of pharmacological properties.

$$19 \quad Rel\ PH = \frac{PH\ of\ a\ given\ plant}{maximum\ PH\ of\ all\ reported\ plant\ species}$$

1 *BS* is the number of body systems treated by a single species and *Rel BS* is the relative
2 number of body systems treated by a single species.

$$3 \quad Rel\ BS = \frac{BS\ of\ a\ given\ plant}{maximum\ BS\ of\ all\ reported\ plant\ species}$$

4 ***Fidelity level (FL)***

5 The fidelity level (FL) index was calculated to check the most preferred plant species used
6 to cure a particular ailment in the study area [56]. The FL value is higher for those plant
7 species that are widely used by local people to treat a particular ailment.

$$8 \quad FL\ (\%) = \left(\frac{Np}{N} \right) \times 100$$

9 Where ‘Np’ is the number of participants citing the use of species for a particular ailment
10 and ‘N’ is the total number of participants citing the use of plant species for any ailments.

11 ***Rahman’s similarity index (RSI)***

12 RSI measures the cultural similarities of indigenous knowledge among the communities of
13 different areas based on common plant species with respect to their uses [57] and is
14 calculated as:

$$15 \quad RSI = \frac{d}{a + b + c - d}$$

16 Where ‘a’ is the number of species unique in area A, ‘b’ is the number of species unique
17 in area B, ‘c’ is the number of species common in both A and B areas and, ‘d’ is the number
18 of common species used for similar ailments in both A and B areas, where $a \& b \neq 0$ and c
19 $\& d \geq 0$.

1 A heatmap showing similarity and dissimilarity value was generated using R-studio [58].
2 Heatmap is a graphical representation of data that utilize colour-coded systems and allows
3 a viewer towards better visualization of the data [59].

4 **Results and Discussion**

5 **Demography of the participants**

6 A total of 50 participants were interviewed representing different ethnic groups, age and
7 gender (Table 1). The participants were grouped into (i) Mongol (Limbu, Rai, Gurung and
8 Sherpa) and Caucasian (Brahmin and Chhetri) based on origin, (ii) age group into younger
9 (≤ 40 years) and older (> 40 years) and (iii) gender into men and women. We performed
10 analysis on the number of medicinal plant species vs ethnicity, age group and gender. The
11 Kruskal-Wallis tests in R studio [58] was applied to calculate the significance level. Unlike
12 other studies, ethnic groups ($\chi^2(1, 50)=2.34$), gender ($\chi^2(1, 50)=0.24$) and age groups ($\chi^2(1,$
13 $50)=0.24$) did not show any statistically significant difference ($p > 0.05$) on the knowledge
14 of medicinal plant species.

15 **Table 1** Demography of the participants

16

17 The study area is inhabited by the indigenous Kirats, Gurungs, Brahmins, Chhetris and
18 other castes [32] making the community heterogeneous. For any particular group,
19 specialists seem to be small in number [60]. We have therefore applied a heterogeneous
20 sampling and included broad groups of participants consisting of traditional healers,
21 herders and local communities. Such a random and broad selection of participants allows

1 a broader dimension of knowledge of plant use within a population [61, 62]. Therefore, the
2 ethnomedicinal knowledge in the study area should have emerged from the interaction of
3 different cultures with the local biophysical environment and biological resources [60, 63].

4 **Diversity of medicinal plant species and their uses**

5 Altogether 140 medicinal plant species, including three pteridophytes species, 1
6 gymnosperm species and 136 angiosperms species belonging to 127 genera and 68 families
7 were reported (Table 2). Thirty families were represented by two or more species, whereas
8 38 families were represented by a single species each (see details in Table 2). Asteraceae
9 and Fabaceae were the dominant families each comprising eight species, followed by
10 Rosaceae and Poaceae each with six species. The therapeutic dominancy of Asteraceae and
11 Fabaceae is associated with the wide and common distribution of the family in Nepal and
12 adjoining areas [64-73].

13 Fifty-five percent of the total medicinal plant species constituted herbs followed by trees
14 (25%), shrubs (11%), and climbers (9%) (Fig. 2). Such dominance of herbs as medicinal
15 plants is comparable with other research findings from Nepal and neighbouring countries
16 [74-78]. Wide distribution and easy access favour the collection of herbs over other life
17 forms such as shrubs and trees [79]. The presence of bioactive compounds like alkaloids,
18 phenolic glycosides and cyanogenic glycosides in herbs [80] makes them able to treat a
19 majority of ailments [81].

20 A total of 83% (116 species) of medicinal plants were harvested by the local communities
21 from the wild, while the remaining 17% (24 species) were cultivated in home gardens.
22 Similar findings have been reported by independent studies from other parts of the world

1 [73, 82-85]. The species harvested from the wild include 110 native species, 2 invasive
2 alien plant species (IAPs) and four naturalized species. The species cultivated in home
3 gardens comprised 18 introduced species and five native species. A wild buckwheat
4 species, *Eskemurkerjea megacarpum* (Polygonaceae), endemic to west and central Nepal
5 [86], was cultivated in the study area for its medicinal value [75]. The majority of the IAPs
6 and naturalized species were used for healing cuts and wounds [64, 67, 68, 77, 78, 87, 88],
7 while the majority of cultivated-introduced species (for example, *Saccharum officinarum*)
8 were used to treat jaundice [87, 89-91] (see Table 2 for details).

9 The majority of the reported medicinal plant species were subtropical and temperate
10 elements. *Achyranthes aspera*, *Acorus calamus* and *Cassia fistula* were the tropical
11 elements used for treating respiratory and gastrointestinal disorders [20, 75, 77, 88, 92, 93-
12 98]. Alpine and subalpine plants growing above 3000 m were also used for treating
13 different human ailments. Timbu Pokhari which is located at an elevation of 4200 m is
14 considered as the prioritized habitat for alpine plant species [99]. This area is the habitat of
15 high altitude medicinal plants like *Aconitum ferox*, *A. heterophylloides*, *Neopicrorhiza*
16 *scrophulariflora*, *Rheum australe*, *R. nobile* and *Saussurea gossypiphora*. The *Aconitum*
17 species, *Neopicrorhiza scrophulariflora*, *Saussurea gossypiphora* were used to treat
18 general disorders like fever and applied during cut and wound [20, 64, 67, 78, 92, 96, 100,
19 101]. A good population of the east Himalayan iconic species '*Rheum nobile*' is found
20 around Timbu Pokhari [99]. The root paste of this species was used to fix the dislocated
21 and fractured bones [96, 101], while the root juice was consumed to reveal back pain and
22 constipation.

Table 2 Medicinal plant species used by the indigenous peoples' and local communities of Chyangthapu-Phalaicha biological sub-corridor

Pr. rem.: Preparation of remedies, Bu (burnt), Co (cooked), Ch (chewing) Es. Ol (essential oil), Ex (extract), Pa (paste), Pi (pickled), Po (porridge), Pw (powder), Ra (raw), Ro (roasted), Sq (squeezed), Va (vapour), Wa (warmed)

Administrative route: O (oral), T (topical), I (inhalation)

Habit: C (climber), H (herb), S (shrub), T (tree)

Habitat: C(e) = cultivated-endemic, C(i) = cultivated-introduced, C(n) = cultivated-native, W(ia) = wild-IAPS, W(na) = wild-native, W(nt) = wild-naturalized

The number and letter in parenthesis after the Latin names represent the voucher specimens number and the housed herbaria respectively.

Fig. 2 Life forms of medicinal plant species in the study area

Utilization of plant parts

Plant parts including the root, rhizome, tuber, stem bark, latex, leaf, aerial shoot, flower, fruit and seed and their exudates were used either singly or in combination with other parts.

The most commonly used plant parts were underground parts i.e. root, rhizome and tuber (33%) followed by leaf (15%), bark (15%), fruit/seed (15%), whole plant (7%), and others (i.e. flower, latex, mature shoot, young shoot, stem, and wool for a collective total of 15%)

(Fig. 3). In some cases, multiple parts of a single species were used, such that the total number of species exceed 140 in the above calculation. The dominant use of underground parts may be linked to the presence of bioactive compounds in these parts [102-103]. These results agree with the previous studies [25, 64, 65, 78, 92, 104-109]. Harvesting of the underground parts must be monitored at regular intervals for the sustainable use of the medicinal plant species [25, 110].

Fig. 3 Number of plant species and parts used

1 Preparation and administration of remedies

2 The indigenous peoples and local communities in the study area use different preparation
3 methods for administering the remedies i.e. extract, chewing, paste, raw, powder, burnt,
4 cooked and others. The most common method of preparing remedies was the extract i.e.
5 decoction, juice and infusion (53%), followed by chewing (19%), paste (12%), raw (4%),
6 powder (3%), burnt and cooked (2% each), and others (5%) (Table 3). Although there was
7 no standardization for remedies administration [8, 102], the quantity and concentration of
8 remedies depended on the age, illness, and diagnosis of the disease [111, 112]. Children
9 were given lower dose, while for adults the type of ailments and their severity were the
10 determining factors [90, 92]. Most of the remedies were given twice a day until recovery
11 [113-115]. The measurement unit was not standardized [82], instead traditional techniques
12 were used for weighing. The extract was either administered using a teaspoon (~ 5 ml) or
13 diluted in a glass of water. Most of these remedies used water as a solvent for extraction.
14 In some cases, honey, cow milk, chicken egg, rock sugar, salt, and mouse droppings were
15 used as additives. For example, a small piece (1 *choito* ~ 5-10 gm) of a rhizome of
16 *Nardostachys jatamansi* was chewed twice a day to treat dysentery. A pinch (1 *chimti* ~ 5-
17 10 gm) bark powder of *Psidium guajava*, dissolved in 500 ml water was consumed twice
18 daily to treat diarrhea and vomiting. One handful (1 *muthi*) leaves of *Taxus wallichiana*
19 was boiled in about 750 ml (1 *mana*) of water, and the extract was consumed twice a day
20 to treat jaundice. A mixture of powdered *Viscum articulatum*, honey (5 ml), cow milk (10
21 ml) and an egg was consumed to treat body pain. In case of hematuria and dysuria, a
22 solution of *Cissampelos pariera*, *Ocimum basilicum*, *Centella asiatica* and rock sugar was
23 left overnight under the open sky and consumed in the early morning. A paste of *Urtica*

1 *parviflora* (root) and mouse droppings was effective against dog bites. Several wild plants
2 were consumed as fresh fruits (*Cassia fistula*, *Euodia fraxinifolia*, *Heracleum nepalense*,
3 *Rhus javanica*), while other plant parts such as tubers (*Nephrolepis cordifolia*),
4 root/rhizome (*Acorus calamus*, *Costus speciosus*, *Nardostachys jatamansi*) and flowers
5 (*Rhododendron arboreum*) were consumed raw for their nutritional and medicinal value.

6 The method of preparing and mode of administering herbal remedies are related to the
7 bioactive compounds present in the plant extract [87, 116]. Oral and topical modes of
8 administration have been the preferred, easiest, and most effective practice in delivering
9 bioactive compounds into the body [76, 87, 102, 106, 107, 117]. In the present study, oral
10 administration was reported for the majority of remedies (63%), followed by topical
11 administration (32%) and inhalation (5%) (Table 4). Nine species were inhaled either as
12 vapour or as smoke. The hot vapour by boiling young shoots of *Justicia adhatoda* and the
13 smoke from burning aerial parts of *Drymaria cordata* were inhaled twice a day to treat
14 sinusitis [118-120]. The smoke of the burnt fruit of *Solanum viarum* was directed towards
15 an infected tooth to overcome the associated pain. The smoke of burnt seeds of *Heracleum*
16 *nepalense* was inhaled to treat sneezing and the common cold [32], indicating that the
17 inhalation mode was used to treat the respiratory disorders.

18 Altogether, 48% (68 species) of the total species cured single ailments, while 29% (40
19 species) cured two ailments and 23% (32 species) cured three or more ailments (Table 2).
20 *Lobelia pyramidalis* cured six ailments, while *Artemisia dubia*, *Astilbe rivularis*,
21 *Rhododendron arboreum*, *Urtica parviflora* and *Zanthoxylum armatum* each cured five
22 ailments. The plant species were used either singly or in combination to treat one or several
23 ailments. For example, *Ficus benghalensis*, *F. religiosa*, *Magnolia champaca*, and

1 *Rhododendron arboreum* were used in combination to treat epileptic disorder. A mixture
2 of *Astilbe rivularis*, *Rheum australe*, and *Viscum articulatum* was used for body pain and
3 ankle sprain. The paste of *Clematis buchananiana*, *Pouzolzia zeylanica*, and *Ulmus*
4 *laceifolia* was useful for bone fracture and dislocation. The solution prepared by mixing
5 *Equisetum diffusum*, *Nasturtium officinale* and *Raphanus sativus* was consumed to treat
6 jaundice. The combined action of different species is believed to increase the catalytic
7 activity of the medicinal constituents and accelerates its assimilation within the body [121].
8 The multiple uses of these species for curing different ailments also reflect their widespread
9 adoption of these species [107].

10 **Table 3** Preparation methods for different remedies

11

12 **Table 4** Administration mode for different remedies

13 **Medicinal plant species and ailment categories**

14 The reported medicinal plant species were used to treat 59 different ailments in the study
15 area. These ailments were categorized into 12 health disorders categories (Table 5). The
16 majority of the plant species were used to treat gastrointestinal disorders (52 species),
17 followed by general disorders (49 species) and respiratory disorders (46 species). The other
18 categories included musculoskeletal disorders (26 species), dermatological disorders (11
19 species), cardiovascular disorders (7 species), genitourinary disorders (6 species), antidote,
20 gynaecological disorders (5 species), neurological and nervous system disorders (5
21 species), sensorial disorders (2 species) and socio-culture bound syndromes (2 species).
22 The prevalence of treatments for gastrointestinal disorders was likely due to malnutrition,
23 poor hygiene, irregular dietary routine and contaminated drinking water [79, 108, 122,

123]. Respiratory disorders can be associated with long-term exposure to indoor air pollution from traditional biomass-based fuelwood burning and tobacco smoking [124-127]. Musculoskeletal disorders could be linked with the region's difficult topography, labor-intensive lifestyle of the local people and the long-term conditions of other pathogenic processes [79, 128].

Quantitative analysis of ethnomedicinal use

Informant consensus factor

Informant consensus factor (ICF) tests the homogeneity of knowledge among participants in the use of plant species to treat particular ailment categories [52, 53]. In this study, the ICF was calculated for 12 health disorders categories, and the range varied from 0 to 0.96 (Table 5). The highest ICF (0.96) was reported for socio-culture bound syndromes and comprised two species (*Heracleum nepalense* and *Ligusticopsis wallichiana*) with 26 use reports. This indicates that the information related to the use of these two species is well exchanged among members of the community. The ICF of musculoskeletal disorders was 0.92 with 26 species and 305 use reports followed by respiratory disorders (0.9) with 46 species and 432 use reports. The ailment category 'sensorial disorders' has the lowest degree of consensus (0) where only two participants cited two plant species (*Artemisia dubia* and *Iresine herbstii*) suggesting no exchange of information about their uses among the participants. The socio-culture bound syndrome was preferably treated with herbal medicine [129] because there is no synthetic treatment available [130]. These species should be given priority as they represent the cultural identity of the area [130, 131].

1 Furthermore, detailed phytochemical screening of species showing high informant
2 consensus can aid in the transfer of local knowledge to the global level [78, 132].

3 **Table 5** Therapeutic/Administration categories of plant species with corresponding
4 informant consensus factor values

5 **Relative frequency of citation**

6 The RFC value showed a wide range varying from 2% to 86%. The most commonly
7 mentioned medicinal plant species was *Swertia chirayita* (43 citations, 86% RFC), which
8 was primarily used for the treatment of fever [64, 87, 92]. This plant is commonly known
9 as a bitter tonic in the traditional medicinal system and is used for the treatment of fever
10 and other ailments [87, 133]. The other most cited species were *Neopicrorhiza*
11 *scrophulariiflora* (42 citations, 84% RFC), followed by *Aconitum laciniatum* and *Viscum*
12 *articulatum* each with 41 citations (RFC 83%), used for the treatment of multiple disorders
13 [20, 65, 74, 75, 78]. These plants have high antimicrobial, antiseptic and anti-inflammatory
14 properties, and were being used for similar therapeutic purposes in different localities [20,
15 21, 87, 92, 134]. The high use value of these species may be attributed to easy availability,
16 common distribution, and widespread information about their therapeutic uses within the
17 community [93]. The RFC of the reported medicinal plant species was 21% on average and
18 only 16.4% species (23 species) have over 25 citations. This indicates that only few species
19 are popular among the local communities, and immediate action is needed to preserve and
20 document the plant species, especially those with high citations and the associated
21 ethnomedicinal knowledge [64]. The RFC of all the reported species is shown in Table 2.

22 **Relative importance**

1 The RI measures the usefulness of the plant species and is derived from several indicators,
2 such as pharmacological properties of the plant species (ailments treated in our case) and
3 the number of body systems treated [55]. The most useful species in our study area were
4 *Artemisia dubia*, *Zanthoxylum armatum* and *Urtica parviflora* (92 each) followed by
5 *Rhododendron arboreum* (82), *Neopicrorhiza scrophulariiflora* and *Astilbe rivularis* (73
6 each) (Table 2). The high RI of these species shows their potential to cure various ailments,
7 possesses strong pharmacological properties, and their wide use by the local communities
8 [55, 102].

9 **Fidelity level**

10 The FL index denotes the most preferred plant species used in the study area to cure a
11 particular ailment [56]. Of the 140 medicinal plant species in total, 36 species were cited
12 by 15 participants or more (Table 6). The major ailment was chosen based on the number
13 of citations. The FL index ranged from 79.49% to 100%. The most preferred medicinal
14 plant species was *Swertia chirayita* which was used to treat fever (100%, 43 citations),
15 followed by *Ageratina adenophora* used to treat cuts and wounds (100%, 35 citations),
16 *Aconitum ferox* used to treat fever (100%, 34 citations), *Saussurea gossypiphora* used to
17 treat cuts and wounds (100%, 33 citations), *Rheum australe* used to treat body pain (100%,
18 31 citations), *Ulmus lanceifolia* used to treat bone fracture and dislocation (100%, 29
19 citations) and others (Table 6). The high popularity of these plant species could be
20 attributed to their high healing potential for a particular ailment and the widespread
21 knowledge among the participants about their uses [102]. However, the plants with low FL
22 or RI value should not be deemed of minor importance. The low value could mean that the
23 traditional knowledge associated with those plant species is not being exchanged or

transmitted and is on the brink of extinction [135]. For example, the leaves of *Artemisia dubia* were heated over fire and applied around the eyes to reduce the pain, but only a single participant cited this therapeutic use. The single citation for this therapeutic use may be because the participant did not share the information, or synthetic drugs replaced its traditional use.

Table 6 Fidelity level of most important plant species in the study area

7

N = the total number of participants citing the plant species for any ailments, N_p = number of participants citing the plant species for a particular ailment. The species are arranged based on the value of 'N' in descending order.

Reliability of indigenous use reports

Indigenous knowledge on traditional medicine is an important part of health care system for a majority of the population living in developing countries [136]. In addition to its potential to discover new therapies [137-139], indigenous knowledge of medicinal plants is known for its socio-economic, conservative and cultural values [136]. However, the indigenous knowledge on medicinal plants varies with socio-economic, demographic, historical and ecological status [140, 141]. Using a certain quantitative index, indigenous knowledge on medicinal plants in one area can be compared with others. A new ethnobiological similarity index, 'Rahman's similarity index (RSI)' [57] has recently been proposed, which compares the present study with published data from an allied, regional, national and global sources.

The reported medicinal plant species were compared to 63 different studies [23, 24, 32, 64-68, 72-78, 84, 85, 87, 89-92, 93-98, 100-107, 135, 142-167] carried out in different parts of Nepal, the Himalayan region, the Tibetan Plateau and East Asia and the Rahman

1 similarity index was calculated. The similarity percentage ranged from 50 to 0 while the
2 dissimilarity percentage ranged from 66.7 to 2.7. The percentage of Rahman similarity
3 varied between 0 and 19.44 among the allied area (Table 7). The highest RSI value (0.19,
4 19.44%) corresponds to the studies in Ilam District, East Nepal [156], followed by the
5 studies in neighbouring districts of Nepal [98, 157, 158] and adjacent areas of the Eastern
6 Himalaya [67, 92]. The similarity index gradually decreased from East to West Nepal and
7 reached zero with the Western Himalaya [72] and East Asian studies [85, 105].

8 A two-dimensional colour chart called ‘heat map’ was generated utilizing the similarities
9 and dissimilarities values in R-studio [58]. The dark blue colour denotes low similarities
10 while dark red colour denotes the high similarities (Fig. 4). The high degree of similarity
11 with the studies in East Nepal and surrounding areas can be attributed to the similar type
12 of vegetation, geography and culture shared among each other [73, 103]. Distantly related
13 culture and the geographical barriers are likely to be the reason for less similarity [168]
14 with the geographically distant studies.

15
16 **Fig. 4** Heat map showing percentage similarity, dissimilarity and Rahman’s similarity
17 index of Chyangthapu-Phalaicha biological sub-corridor with neighbouring areas

18 Comparative analysis of this study with published literature [20, 23, 24, 32, 64-68, 72-78,
19 84, 85, 87-92, 93-98, 100-107, 135, 142-167, 169-171] revealed novel therapeutic uses for
20 41 ailments associated with 52 plant species (denoted as NR in Table 2). The newly
21 documented use reports need further phytochemical research to validate the traditionally
22 used system [172], which can provide new insights into medical sciences [137].

1 About 80% of the population of Nepal depends on traditional medicine [173] and 54% of
2 traditional remedies are derived from plants [22]. Given that the large proportion of plant
3 species used in traditional health care in Nepal, documentation and bioprospecting the
4 medicinal plants is most important. Developing a herbal processing unit at local level can
5 be an efficient and cost-effective practices [174]. This will provide the local communities
6 with an alternative source of income, while also ensuring a better public health in the
7 communities [175].

8 **Table 7** Rahman's similarity index comparing the present study with previous studies

9 NRSAA: number of recorded plants species of aligned areas, TSCBA: Total species common in both area,
10 SEOAA: Species enlisted only in aligned areas, SEOOA: Species enlisted only in our study area, CSSU:
11 Common species with similar uses, % PSU: % of plant with similar uses, % PDU: % of plant with dissimilar
12 uses

13 **Threats to ethnomedicinal plant species and conservation practices**

14 Although over 2,000 plant species are used to treat various therapeutic ailments in Nepal
15 [20-23], many people continue to suffer from various diseases each year. Poverty, lack of
16 modern health care and sanitation facilities, and poor governance are among the most
17 important reasons [25]. The distribution of medicinal plants and associated indigenous
18 knowledge is not uniform across the country [176], and a huge gap in knowledge sharing
19 has been observed within different communities [20, 109, 176]. Traditional knowledge
20 transmission is declining primarily due to rapid innovations in modern allopathic medicines
21 and changes in social trends and cultural beliefs [177].

22 Medicinal plants and biodiversity are threatened by habitat fragmentation and degradation
23 within the Chyangthapu-Phalaicha biological sub-corridor. The ongoing developmental
24 process, such as highway construction through prime forests and red panda (*Ailurus*

1 *fulgens*) habitat and the construction of several rural roads without proper environmental
2 impact assessment, is a major cause of habitat fragmentation. Furthermore, the increased
3 vehicle traffic along this highway is also likely to cause both physical and mental
4 disturbances to the wildlife in the area. The areas adjacent to the Chyangthapu-Phalaicha
5 biological sub-corridor, i.e. the Barsey Rhododendron Sanctuary in Sikkim and Singhalila
6 National Park in West Bengal, are managed by the Government of India as protected areas.
7 Unlike these areas in KL-India, the protection and monitoring of the Chyangthapu-
8 Phalaicha biological sub-corridor is fairly low in Nepal [35], which has seriously
9 jeopardize the habitat of high altitude medicinal species, for example, *Aconitum* species,
10 *Rheum* species, *Saussurea gossypiphora*, *Nardostachys jatamansi* and *Neopicrorhiza*
11 *scrophulariiflora*.

12 **Conclusion**

13 The diversity and importance of medicinal plants in the Chyangthapu-Phalaicha biological
14 sub-corridor to treat various ailments in traditional health care were assessed. A total of
15 140 plant species used to treat various human ailments were documented. Therapeutic uses
16 for 41 ailments associated with 52 plant species were newly reported.

17 Our results suggest that the use of medicinal plant knowledge in the Chyangthapu-
18 Phalaicha biological sub-corridor is well preserved. However, the prevailing conservation
19 challenges were habitat fragmentation and degradation. Those challenges can be mitigated
20 by the restoration of the habitat and by the domestication of medicinal plants in the sub-
21 corridor. This will promote the transfer of indigenous knowledge to future generations,
22 thereby safeguarding the local biological resources and the associated indigenous
23 knowledge. Establishing processing units at the local level is a logical follow-up to the

1 cultivation of medicinal plants. This will not only preserve the local plant resources but
2 also create job opportunities at the local level, which will potentially help to reduce the
3 youth out-migration for foreign employment. We also recommend conducting
4 phytochemical and pharmacological screening for the most promising plant species,
5 particularly those with a high value of ethnobotanical indices, which can aid the transfer of
6 local knowledge to the global community.

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14 **Author's contributions**

15 PB conducted field survey, gathered and analyzed data, and prepared the manuscript's first
16 draft. MBG, CKS, KB, RPC, JG, YU, AN and KKS contributed to research design, field
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25 **Availability of data and materials**

1 We have included all the data in the manuscript.

2 **Ethics approval and consent to participate**

3 A prior informed consent was sought from the concerned authorities and all the
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5 **Consent for publication**

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7 **Competing interests**

8 The authors declare that they have no competing interests.

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Figures

Figure 1

Map of study area: A. Nepal, B. Kangchenjunga Landscape (source: [31]), C. East Nepal Conservation Corridor, D. Yangawarak RM. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square

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Figure 2
Life forms of medicinal plant species in the study area

Figure 3

Number of plant species and parts used

Figure 4

Heat map showing percentage similarity, dissimilarity and Rahman's similarity index of Chyangthapu-Phalaicha biological sub-corridor with neighbouring areas