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Original Article

Species composition of the vegetation along the Sherichhu River, lower montane area of Eastern Bhutan

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Abstract

An investigation of the riparian vegetation along the Sherichhu River, lower montane area of Eastern Bhutan was conducted from April to December 2015 to explore the plant communities in terms of species composition. A total number of 18 plots were placed within the remnant patches of the vegetation on either side of the river. In total, 172 species of vascular plant has been recorded. The cluster analysis suggested four types of plant communities in the study area viz., the *Mallotus-Desmodium-Rhus* shrubland and the *Syzygium venosum* woodland communities, which are located in V-shaped valleys and the *Albizia-Flueggea* woodland and *Quercus glauca* woodland communities located in U-shaped valleys. In broad-spectrum, the topographic features and environmental variables i.e. litter accumulation and flooding condition might also have some impact on the species composition of the plant communities of this vegetation.

Keywords: Sherichhu River, Bhutan, riparian vegetation, species composition, litter thickness

1. Introduction

Bhutan is positioned within the fledgling mountain range of the Eastern Himalayas with an area of 38,394 km^2. The country is gifted with rich natural resources and plant diversity. About 72.5% of physiological area in Bhutan is covered by forest including shrubs with an altitudinal gradient from 150 to 7,500 meters above sea level (masl) (Roder *et al.*, 2002). Forests in Bhutan are classified into three broad and distinct eco-floristic zones; alpine forests (above 4,000 masl), temperate forests (2,000-4,000 masl), and sub-tropical forests (500-2,000 masl) (Oshawa *et al.*, 1987). The broad-leaved forest is the most widespread forest type, accounting for 62% of forested area, which are very rich in species of both sub-tropical and temperate genera (Roder & Frei, 2013). In any case, only few studies are concerned about the vegetation accounting mainly on the temperate and alpine region along the altitudinal gradient of Bhutan (Grieson & Long, 1983; Hara, 1991; Jamtsho, 2015; Ohsawa *et al.*, 1987; Sargent, 1985; Wangchk *et al.*, 2014; Wangda & Ohsawa, 2006).

With the landscape of Bhutan being characterized by rugged mountains separated by river valleys, several types of riparian vegetation are present along the valleys of different areas from the subtropical ones through to the temperate ones, then up to an exclusively alpine region. This riparian vegetation has accommodated various numbers of plants as well as wildlife. Moreover, many of ancient routes of trade and communication in this region of the Himalayan areas were here as one could recognize only by archeological relics e.g. old pagodas (the "Chorten" in Dzongkha), which were often found along streams in remote areas of Bhutan. In any case,

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there is a lack of sufficient literature as many researchers did not pay consideration on such types of vegetation.

The present study was conducted in order to describe the vegetation composition, plant communities of the unexplored riparian vegetation of the lower montane areas of eastern Bhutan Himalaya as an important basic database to support not only the sustainable use of the plant resources of the Himalaya in future, but also to provide a fundamental information of this rare habitat of the Himalayan areas in general.

2. Methods

2.1 Study area

The study was conducted along the "*Sherichhu River"* (27°15'-27°21' N, 91°24'-91°24' E), located in Mongar district, Eastern Bhutan (Figure 1). The forest along the Sherichhu River was selected as being representative for the present study due to its variability including non-disturbed versus disturbed situation as well as its most easily accessible and least risky among all rivers surveyed in eastern Bhutan. The upper half of the study area is positioned in the Bomdeling Wild Life Sanctuary, which ranges from the lower broadleaved forests to the alpine ecosystem, while the lower half of the river is not included in the protected area, therefore, some anthropogenic influences from animal grazing and looping occurred occasionally. The study area is ca. 15 km in length, ranging from 540 to 1,450 masl. The climate of the area is humid subtropical monsoon with a mean temperature of 20°C. The annual rainfall is 1,200-1,500 mm with the heaviest rainfall in July (National Statistics Bureau, 2014).

2.2 Landscape and study plots

The landscape of the surrounding vegetation was characterized by sharp ridges, high hills, and narrow valley, where meandering river had created narrow flood plains and levees at different locations. There was prominent deposition of the silt, pebbles, cobbles, and huge rocks of varying size along either side of the river having riparian vegetation. The topography has supported different plant habitats, viz., woodland, shrubland, open ground and transitional vegetation between aquatic and terrestrial habitats. Eighteen study plots (size 15 m x 25 m) were designated in accordance with the Braun-Branquet approach (Kent & Coker, 1994) within the remnant patches of the vegetation on either side of the river, which was assumed as representative of riparian plant community. Patches were distinct in floristic composition and physical appearances from the surrounding vegetation. Plots were laid on the accessible locations of the vegetation along the river (Figure 1C). However, study sites were assigned to cover all landscape types found along the river, which would then characterize the fast flowing river of these lower montane areas of the Himalaya. For example, plots 1-8 are located along either site of the Sherichhu River where in sharp valleys

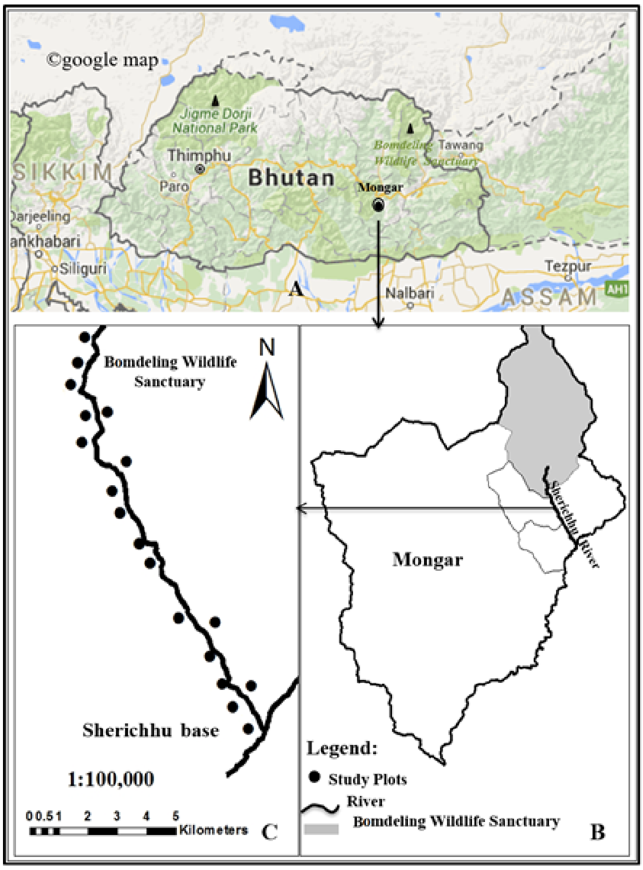

Figure 1. A: Map of Bhutan with Mongar district. B: Map of Mongar district showing Sherichhu River. C; Sherichhu River and study plots.

without any curves or sedimentation plain, "V-shape" valleys in the present study, whereas plots 11-18 (plots 13-18 fall within the BWS) are located in valleys with small basins/ plains where the river may have twisted and therefore marked a curve where sedimentation occurred, "U-shaped Valley" in the present study. In such valley type old depositional plains were achieved by the river (Figure 2). In addition, plots 9-10 were laid on the river bank in a connective part of the river from a "V-shaped" to a "U-shaped" valley (Figure 2). Locations of the plots were limited to places right at the edge of the river bank up to 50 m in a perpendicular line to the edge of the river bank and being laid subjectively (Kent & Coker, 1994) in selected places along the length of the Sherichhu River where relics of natural vegetation occurred.

2.3 Data collection

Plant surveys as well as the collection of selected environmental parameter, i.e. altitude, slope, aspect, and litter thickness, were carried out from April to December 2015 to ensure full coverage of the flowering season. Altitude was measured using global positioning system, aspect was measured using Suntos compass, slope was measured using Suntos clinometer, and litter thickness was determined by

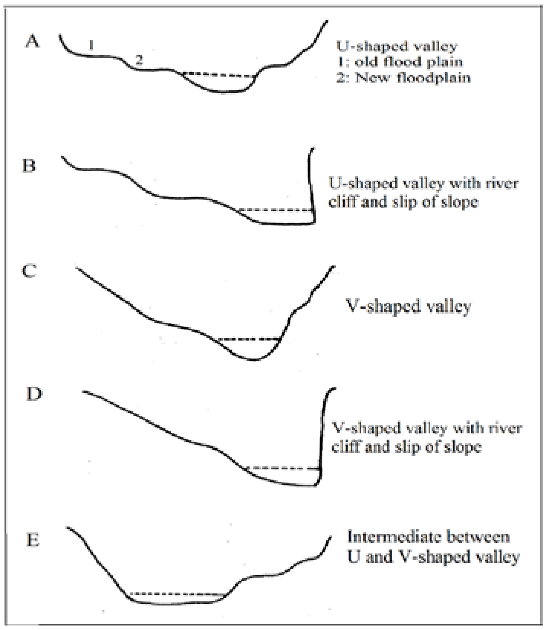

Figure 2. Cross section of the Sherichhu River valley showing various topographic features (A and B: U-shaped valley; C and D: V- shaped valley; E: Intermediate form between U- and V-shaped valley).

ruler (Zhang *et al.*, 2006, 2013). The altitude, slope, and litter thickness were in reading values, while the aspect measurement was classified from 1 to 8:1 (0°-45°), 2 (46°-90°), 3 (91°-135°), 4 (136°-180°), 5 (181°-225°), 6 (226°-270°), 7 (271°-315°), and 8 (316°-360°) (Zhang *et al.*, 2013). All individual plants in each plot were recorded as well as the ones occurring adjacent to the plots in order to obtain the complete checklist of the plant diversity along the river. Plant specimens collected were identified using available taxonomic literature. The voucher specimens were deposited at the National Herbarium in Serbithang, Thimphu district, Bhutan.

2.4 Data analysis

In order to distinguish the plant communities, cluster analysis using average linkage method was applied. Sørensen similarity coefficient was calculated in order to find the similarities among those selected plots. The canonical correspondence analysis (CCA) ordination was done to achieve the species composition as well as any effect of environmental variables (altitude, litter, aspect, and slope) to the species composition. However, the less common found species were not included in the CCA analysis to minimize their effect on the data (Oksanen, 2015). The correlation and regression were executed to analyze relationship of environmental variables to the species richness. The floristic richness was determined by the direct computation of the number of species, genera, and families recorded. The analysis was performed by using software R Version 3.0.0. (R Development Core Team, 2013).

3. Results

3.1 Species richness

A total of 172 vascular plants species belonging to 149 genera and 71 families were recorded (Table 1). Among them, 162 species are angiosperms (134 Eudicots and 26 Monocots) and 10 species are monilophytes belonging to 9 families and 9 genera. The most diverse family in the present study was Fabaceae (18 species), followed by Rubiaceae (10 species), Malvaceae and Cyperaceae (8 species each), and Orchidaceae (6 species), respectively. Tree species contributed 19.41% of the overall plant species in this gallery forest, while the shrub, herb, liana and fern had contributed 31.18%, 37.05%, 7.05%, and 5.29%, respectively.

3.2 Plant communities and their species composition

The cluster analysis and the Sørensen similarity coefficient recognized four different plant communities that characterized the riparian vegetation along Sherichhu River of Eastern Bhutan Himalaya (Figure 3). Considering the Sørensen similarity, the highest similarity was recognized between plot 17 and 18 (76%), while the lowest one could be seen between plot 4 and 17, 5, and 17 (11% each) (Table 2). Generally, there are two different main riparian plant community types along this Sherichhu River (one of those represented by plot 1 to 9 and the other represented by plot 10-18), which could be according to the topography features (U and V shaped valley; Figure 2 and 4). Four plant community types were recognized along the Sherichhu River, one of which is woodland, while the others are shrubland. These plant communities were named after the dominant plant species as follows:

1) Mallotus-Desmodium-Rhus shrubland (Plot 1-5 and 6): This community is situated along a river that flows through V- shape valleys. The valley is with the distinct levees on both sides of the river composed of the pebbles, cobbles and boulders, where deposition of degraded litter/silt/soil has taken place and it has supported growth of plant species forming the riparian plant community. This plant community type is dominated by the shrubby and/or small tree species i.e. *Mallotus philippensis* (Lam.). Müll.Arg, *Litsea glutinosa* (Lour.) C.B.Rob. and *Rhus paniculata* Wall. ex G. Don with more/less open canopy (Figure 3 and 4B).

2) Syzygium venosum woodland (Plot 7-9): This plant community is also situated in the V-shaped valley with various patches of alluvial plains formed on either side of the river. Sites of such communities were characterized by pebbles, cobbles, boulders, and the emergent rocks, especially, distinct in winter when the water level decreases. These patches of small alluvial plains on either side of the river had accommodated plant communities that were characterized by an "asymmetric" canopy size and often with a diagonally leaning trunk towards the river (Figure 3). This is dominated by *Syzygium venosum* DC., *Duabanga grandiflora* (DC.)

Table 1. List of all plant species recorded in the riparian forest along the study site.

Family	Scientific name	Abb.[1]	Life form	Study plots																		Voucher
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Monilophytes																						
Equisetaceae	*Equisetum hyemale* L.	equ.hye	F	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	T.Jam188
Ophioglossaceae	*Ophioglossium* sp.	oph.sp	F	x	x																	T.Jam184
Anacardiaceae	*Rhus paniculata* Wall. ex G. Don	rhu.pan	S	x	x	x		x	x	x	x	x		x	x	x			x	x		T.Jam181
Asparagaceae	*Asparagus racemosus* Willd.	asp.rac	S	x	x	x	x	x	x		x											T:Jam375
Asteraceae	*Acmella uliginosa* Cass.	acm.uli	H	x		x									x				x			T.Jam183
Asteraceae	*Bidens bipinnata* Baill.	bid.bip	H	x		x			x							x			x	x	x	T.Jam193
Asteraceae	*Inula cappa* (Buch.-Ham. ex D.Don) DC.	inu.cap	S	x	x		x		x													T.Jam180
Caryophyllaceae	*Sagina japonica* (Sw. ex Steud.) Ohwi	sag.jap	H	x																		T.Jam253
Euphorbiaceae	*Euphorbia hirta* L.	eup.hit	H	x	x		x	x	x	x	x											T.Jam173
Fabaceae	*Abrus precatorius* L.	abr.pre	H	x			x	x														T.Jam112
Fabaceae	*Crotalaria calycina* Schrank	cro.cal	H	x			x	x		x	x	x										T.Jam320
Fabaceae	*Desmodium confertum* DC.	des.con	S	x	x	x	x	x														T.Jam379
Fabaceae	*Desmodium elegans* DC.	des.ele	S	x	x	x	x	x		x	x					x						T.Jam043
Fabaceae	*Flemingia macrophylla* (Willd.) Prain	fle.mac	S	x				x	x	x	x	x	x			x		x	x	x	x	T.Jam380
Lythraceae	*Woodfordia fruticosa* (L.) Kurz	woo.fru	S	x	x	x	x															T.Jam042
Moraceae	*Ficus squamosa* Roxb.	fic.squ	S	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	T.Jam047
Euphorbiaceae	*Mallotus philippensis* (Lam.).Müll.Arg.	mal.phi	T		x	x	x	x	x	x	x		x	x						x	x	T.Jam046
Fabaceae	*Albizia lebbeck* (L.) Benth.	alb.leb	T		x					x			x									T.Jam038
Fabaceae	*Crotalaria sessiliflora* L.	cro.ses	H		x				x	x		x										T.Jam317
Fabaceae	*Indigofera cassioides* Rottler ex DC.	ind.cass	S		x																	T.Jam047
Flacourtiaceae	*Flacourtia jangomas* Raeusch.	fla.jan	S		x	x													x	x		T.Jam040
Lamiaceae	*Holmskioldia sanguinea* Retz.	hol.san	S		x		x															T.Jam156
Malvaceae	*Sida cordata* (Burm.f.) Borss.Waalk.	sid.cor	H		x		x		x													T.Jam351
Menispermaceae	*Cissampelos pareira* L.	ciss.par	L		x	x	x	x	x													T.Jam117
Moraceae	*Ficus semicordata* Buch.-Ham. ex Sm.	fic.sem	T		x	x	x															T.Jam168
Salicaceae	*Flacourtia jangomas* (Lour.) Raeusch.	fla.jan	S		x	x													x	x		T.Jam040
Santalaceae	*Osyris lanceolata* Hochst. & Steud.	osy.lan	S		x		x	x	x													T.Jam049
Cannabaceae	*Trema politoria* (Planch.) Blume	tre.pol	S		x																	T.Jam120
Vitaceae	*Ampelocissus divaricata* (Wall. exM. A.Lawson) Planch.	amp.div	L		x	x			x					x	x	x				x	x	T.Jam248
Cyperaceae	*Eriophorum comosum* (Wall.)Nees	eri.com	H		x	x																T.Jam324
Acanthaceae	*Barleria cristata* L.	bar.cri	H			x																T:Jam355
Apocynaceae	*Wrightia arborea* (Dennst.) Mabb.	wri.adb	T			x	x	x	x													T.Jam157
Salicaceae	*Casearia glomerata* Roxb.	cas.glo	S			x			x	x					x	x				x		T.Jam067
Phyllanthaceae	*Glochidion velutinum* Wight	glo.vel	T			x	x		x													T.Jam111
Poaceae	*Pogonatherum paniceum* (Lam.) Hack.	pog.pan	H			x	x		x	x							x		x	x	x	T.Jam037

Table 1. Continued

Family	Scientific name	Abb.[1]	Life form	Study plots																		Voucher
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Apocynaceae	*Cryptolepis buchananii* Roem. & Schult.	cry.buc	S				x	x	x													T.Jam052
Malvaceae	*Urena lobata* L	ure.lob	H				x	x	x							x						T.Jam165
Cyperaceae	*Eleusine indica* (L.) Gaertn.	ele.ind	H				x	x		x		x	x	x				x	x			T.Jam294
Poaceae	*Arundinella pumila* (Hochst. ex A. Rich.) Steud.	aru.pum	H				x	x	x	x	x	x							x			T.Jam243
Fabaceae	*Albizia lucidior* (Steud.) I.C. Nielsen	alb.luc	T					x					x	x			x	x				T.Jam092
Loranthaceae	*Scurrula pulverulenta* (Wall.)G. Don	scu.pul	E					x	x	x												T.Jam349
Malvaceae	*Grewia venusta* Fresen.	gre.ven	T					x														T.Jam041
Phyllanthaceae	*Bridelia retusa* (L.) A. Juss.	bri.ret	T					x														T.Jam326
Rubiaceae	*Ixora undulata* Roxb.	ixo.und	T					x														T.Jam158
Sapotaceae	*Diploknema butyracea* (Roxb.) H.J.Lam	dip.but	T					x								x						T.Jam161
Poaceae	*Digitaria ciliaris* (Retz.) Koeler	dig.cil	H					x		x	x	x										T.Jam295
Lomariopsidaceae	*Nephrolepis cordifolia* (L.) C. Presl	nep.cord	F						x	x	x	x				x			x	x	x	T.Jam277
Ericaceae	*Viburnum* sp.	vib.sp	S						x													T.Jam134
Malvaceae	*Kydia calycina* Roxb.	kyd.cal	T						x								x					T.Jam363
Melastomataceae	*Melastoma normale* D.Don	mel.nor	S						x	x	x	x										T.Jam057
Phyllanthaceae	*Flueggea virosa* (Roxb. ex Willd.) Voigt	flu.vir	S						x		x		x			x	x	x				T.Jam126
Bignoniaceae	*Oroxylum indicum* (L.) Benth. ex Kurz	ory.ind	T							x												T.Jam383
Euphorbiaceae	*Sapium insigne* (Royle) Benth. & Hook.f.	sap.ins	T							x		x	x	x		x	x		x	x	x	T.Jam075
Linderniaceae	*Torenia violacea* (Azaola ex Blanco) Pennell	tor.vio	H							x	x	x										T.Jam288
Cyperaceae	*Cyperus compressus* L.	cyp.com	H							x	x	x	x									T.Jam220
Cyperaceae	*Cyperus odoratus* L.	cyp.odo	H							x	x	x										T.Jam291
Cyperaceae	*Fimbristylis littoralis* Gaudich.	fim.lit	H							x	x	x			x	x						T.Jam292
Combretaceae	*Terminalia myriocarpa* Van Heurck & Müll. Arg.	ter.myr	T								x	x										T.Jam359
Elaeagnaceae	*Elaeagnus parvifolia* Wall.	ela.par	S								x	x										T.Jam065
Fabaceae	*Bauhinia purpurea* L.	bau.pur	T								x		x	x		x	x	x	x	x	x	T.Jam249
Fabaceae	*Butea buteiformis* (Voigt) Grierson	but.but	S								x	x				x	x					T.Jam254
Lythraceae	*Duabanga grandiflora* (DC.) Walp.	dua.gra	T								x	x										T.Jam053
Melastomataceae	*Oxyspora paniculata* (D. Don) DC	oxy.pan	S								x											T.Jam234
Myrtaeae	*Syzygium venosum* DC.	syz.ven	T								x	x		x	x	x			x	x		T.Jam114
Saururaceae	*Houttuynia cordata* Thunb.	hou.cor	H								x	x										T.Jam238
Cyperaceae	*Cyperus cyperoides* (L.) Kuntze.	cyp.cyp	H								x	x		x								T.Jam218
Vitaceae	*Tetrastigma rumicispermum* (M.A. Lawson) Planch.	tet.rum	L								x			x	x					x		T.Jam150
Acanthaceae	*Justicia adhatoda* L.	jus.adh	S									x	x	x								T.Jam107
Apiaceae	*Hydrocotyle himalaica* P.K.Mukh.	hyd.him	H									x			x							T.Jam296
Malvaceae	*Sida acuta* Burm. f.	sid.acu	H									x		x								T.Jam187

Table 1. Continued

Family	Scientific name	Abb.[1]	Life form	Study plots																		Voucher
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Phyllanthaceae	*Bridelia sikkimensis* Gehrm.	bri.sik	T									x					x		x	x		T.Jam352
Polygonaceae	*Persicaria nepalensis* (Meisn.) Miyabe	per.nep	H									x		x	x	x		x	x	x	x	T.Jam124
Rutaceae	*Citrus medica* L.	cit.med	S									x		x				x	x			T.Jam068
Cyperaceae	*Cyperus rotundus* L.	cyp.rot	H									x	x									T.Jam290
Cyperaceae	*Setaria pumila* (Poir.) Roem. & Schult.	set.pum	H									x										T.Jam293
Poaceae	*Imperata cylindrica* (L.) P. Beauv.	imp.cyl	H									x										T.Jam361
Cornaceae	*Alangium alpinum* (C.B.Clarke) W.W.Sm. & Cave	ala.alp	T										x				x					T.Jam050
Bignoniaceae	*Radermachera sinica* Hemsl.	rad.sin	T										x					x				T.Jam066
Caesalpiniaceae	*Caesalpinia decapetala* (Roth) Alston	cae.dec	S										x									T.Jam062
Convolvulaceae	*Ipomoea purpurea* (L.) Roth	ipo.pur	L										x					x	x			T.Jam354
Fabaceae	*Albizia odoratissima* (L.f.) Benth.	alb.odo	T										x									T.Jam166
Fabaceae	*Pterolobium hexapetalum* (Roth) Santapau & Wagh	pte.hex	H										x	x								T.Jam076
Primulaceae	*Maesa chisia* D.Don	mae.chi	S										x			x		x	x			T.Jamo70
Rhamnaceae	*Ziziphus incurva* Roxb.	ziz.inc	T										x	x	x	x	x		x	x		T.Jam135
Rubiaceae	*Pavetta indica* L.	pav.ind	T										x	x								T.Jam201
Cannabaceae	*Celtis tetrandra* Roxb.	cel.tet	T										x		x		x	x				T.Jam143
Aspleniaceae	*Asplenium australasicum* (J. Sm.) Hook.	asp.aus	F											x		x				x	x	T.Jam104
Davalliaceae	*Davallia canariensis* (L.) Sm.	dav.can	F											x	x	x			x	x	x	T.Jma106
Polypodiaceae	*Polypodium cambricum* L.	pol.cam	F											x	x				x	x	x	T.Jam276
Anacardiaceae	*Rhus chinensis* Mill.	rhu.chi	T											x	x							T.Jam339
Capparaceae	*Capparis acutifolia* Sweet	cap.acu	S											x								T.Jam061
Fagaceae	*Quercus glauca* Thunb.	que.gla	T											x	x	x			x	x	x	T.Jam056
Gesneriaceae	*Lysionotus serratus* D.Don	lys.ser	H											x	x	x				x	x	T.Jam283
Malvaceae	*Pterospermum acerifolium* (L.)Willd.	pte.ace	T											x								T.Jam131
Meliaceae	*Toona ciliata* M. Roem.	too.cil	T											x								T.Jam039
Oleaceae	*Jasminum laurifolium* Roxb. ex Hornem.	jas.lau	S											x	x	x	x	x	x	x		T.Jam141
Piperaceae	*Piper boehmeriifolium* (Miq.) Wall. ex C. DC.	pip.boe	H											x	x	x				x	x	T.Jam080
Piperaceae	*Peperomia tetraphylla* (G.Forst.) Hook. & Arn.	pep.tet	H											x	x	x				x	x	T.Jam144
Rubiaceae	*Galium elegans* Wall. ex Roxb.	gal.ele	H											x		x				x	x	T.Jam312
Rubiaceae	*Ophiorrhiza fasciculata* D. Don	oph.fas	H											x		x				x		T.Jam224
Rubiaceae	*Catunaregam longispina* (Roxb. Ex Link) Tirveng.	ran.spi	S											x	x				x			T.Jam108
Solanaceae	*Solanum erianthum* D. Don	slo.eri	S											x								T.Jam058
Solanaceae	*Solanum viarum* Dunal	slo.via	H											x	x							T.Jam227
Urticaceae	*Pilea umbrosa* Blume	pil.umb	H											x	x	x				x	x	T.Jam267
Costaceae	*Costus lacerus* Gagnep.	cos.lac	H											x								T.Jam264

Table 1. Continued

Family	Scientific name	Abb.[1]	Life form	Study plots																		Voucher
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Dioscoreaceae	*Dioscorea hamiltonii* Hook. f.	dio.ham	L											x				x				T.Jam305
Orchidaceae	*Rhynchostylis retusa* (L.)Blume	rhy.ret	H											x								T.Jam129
Orchidaceae	*Schoenorchis gemmata* (Lindl.) J.J. Sm.	sch.gem	H											x	x	x	x		x	x	x	T.Jam130
Adiantaeae	*Adiantum lunulatum* Burm.f.	adi.lun	F												x				x	x	x	T.Jam313
Polypodiaceae	*Pleopeltis macrocarpa* (Bory ex Willd.) Kaulf.	ple.mac	F												x	x			x	x	x	T.Jam274
Acanthaceae	*Strobilanthes flexicaulis* Hayata	str.fle	H												x				x			T.Jam335
Fabaceae	*Dalbergia sericea* Bojer	cal.ser	T												x					x		T.Jam045
Gesneriaceae	*Chirita bifolia* D.Don.	chi.bif	H												x				x	x	x	T.Jam223
Lamiaceae	*Clerodendrum colebrookianum* Walp.	cle.col	S												x							T.Jam325
Malvaceae	*Grewia sepiaria* Roxb. & G.Don	gre.sep	T												x		x		x			T.Jam306
Rubiaceae	*Luculia gratissima* (Wall.) Sweet	luc.gra	S												x							T.Jam358
Rutaceae	*Zanthoxylum armatum* DC.	zan.arm	S												x		x	x	x			T.Jam233
Araceae	*Remusatia vivipara* (Roxb.) Schott	rem.viv	H												x	x			x	x	x	T.Jam271
Burmanniaceae	*Burmannia liukiuensis* Hayata	bur.liu	H												x					x		T.Jam316
Commelinaceae	*Commelina paludosa* Blume	com.pal	H												x				x	x	x	T.Jam229
Orchidaceae	*Oberonia acaulis* Hook.	obe.aca	H												x				x		x	T.Jam299
Asparagaceae	*Ophiopogon japonicus* (Thunb.) Ker Gawl.	oph.jap	H													x			x	x	x	T.Jam281
Ericaceae	*Vaccinium vacciniaceum* (Roxb.) Sleumer	vac.vac	S													x			x	x	x	T.Jam096
Euphorbiaceae	*Macaranga denticulata* (Blume) Müll.Arg.	mac.den	T													x						T.Jam210
Fabaceae	*Desmodium laxum* DC	des.lax	S													x	x		x	x	x	T.Jam307
Fabaceae	*Tephrosia candida* DC.	tep.can	T													x						T.Jam340
Juglandaceae	*Engelhardia spicata* Blume	eng.spi	T													x						T.Jam072
Acanthaceae	*strobilnthes* sp.	str.sp	H														x	x	x	x	x	T.Jam372
Actinidiace	*Saurauia roxburghii* Wall.	sau.rox	S														x	x				T.Jam059
Apocynaceae	*Matelea carolinensis* (Jacq.) Woodson	mat.car	H														x	x	x	x		T.Jam230
Celastraceae	*Maytenus hookeri* Loes.	may.hoo	S														x					T.Jam132
Convolvulaceae	*Dinetus racemosa* (Wall.) Sweet	din.rac	H														x		x			T.Jam364
Convolvulaceae	*Ipomoea grandifolia* (Dammer) O'Donell	ipo.gra	L														x	x				T.Jam309
Fabaceae	*Millettia pachycarpa* Benth.	mil.pac	H														x		x			T.Jam081
Melastomataceae	*Osbeckia nepalensis* Hook.f.	osb.nep	S														x					T.Jam319
Moraceae	*Morus australis* Poir.	mor.aus	S															x				T.Jam142
Zingiberaceae	*Hedychium coccineum* Buch.-Ham. ex Sm.	hed.coc	H															x	x	x	x	T.Jam284
Commelinaceae	*Cyanotis vaga* (Lour.) Schult. & Schult. f.	cya.vag	H															x	x	x		T.Jam272
Orchidaceae	*Eria pulchella* Lindl.	eri.pul	H															x				T.Jam240
Aspleniaceae	*Asplenium pteropus* Kaulf.	asp.pte	F																x		x	T.Jam310
Actinidiacea	*Saurauia napaulensis* DC.	sau.nap	S																x	x		T.Jam203
Araliaceae	*Schefflera elliptica* (Blume) Harms	sch.ell	E																x	x	x	T.Jam381
Asparagaceae	*Tupistra nutans* Wall. ex Lindl.	tup.nut	H																x	x	x	T.Jam105

Table 1. Continued

Family	Scientific name	Abb.[1]	Life form	Study plots																		Voucher
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Euphorbiaceae	*Ostodes paniculata* Blume	ost.pan	T																x			T.Jam051
Gesneriaceae	*Aeschynanthus parviflorus* (D. Don) Spreng.	aes.par	H																x	x	x	T.Jam231
Malvaceae	*Sterculia hamiltonii* (Kuntze) Adelb.	ste.ham	T																x	x		T.Jam341
Linderniaceae	*Lindernia antipoda* (L.) Alston	lin.ant	H																x			T.Jam298
Araceae	*Rhaphidophora grandis* Schott	rha.gra	H																x	x	x	T.Jam103
Orchidaceae	*Calanthe triplicata* (Willemet) Ames	cal.tri	H																x	x	x	T.Jam091
Polypodiaceae	*Microsorum musifolium* (Blume) Copel.	mic.mus	F																	x		T.Jam275
Balanophoraceae	*Balanophora dioica* R.Br. ex Royle	bal.dio	H																	x		T.Jam378
Fabaceae	*Entada rheedii* Spreng.	ent.rhe	L																	x	x	T.Jam133
Rubiaceae	*Chassalia curviflora* (Wall.) Thwaites	cha.cur	H																	x	x	T.Jam219
Rubiaceae	*Ixora* sp.	ixo.sp	T																		x	T.Jam136
Rubiaceae	*Wendlandia grandis* Cowan	wen.gra	T																		x	T.Jam137
Theaceae	*Schima wallichii* (DC.) Korth.	sch.wal	T																	x	x	T.Jam140
Lauraceae	*Lindera bootanica* Meisn.	lin.boo	T																	x	x	T.Jam036
Orchidaceae	*Malaxis josephiana* (Rchb.f.) K.M.Matthew	mal.jos	H																		x	T.Jam285

Note; Abb. = abbreviation of species name, T= tree, S = shrub, H = herb, L = liana, F = fern, x = presences of species

Walp. and *Terminalia myriocarpa* Van Heurck & Müll. Arg. (Figure 3 and 4).

3) The Albizia-Flueggea woodland (Plot 10, 14 and 15): This community is situated within the U-shaped valleys along the river bed with more or less open canopy vegetation. In general, the river bank, where such community was situated, is composed of degraded litter as well as pebbles and cobbles. The river floor is mostly composed of boulders and gravels that scraped each other, thereby depositing more sand and silt along the river. This community is dominated by *Albizia lucidior* (Steud.) I.C. Nielsen and *Flueggea virosa* (Roxb. ex Willd.) Voigt.

4) The Quercus glauca woodland (Plot 11-13 and 16-18): The *Quercus glauca* woodland community is also situated in the U-shaped valleys along the riverbanks of the upper most part, where the river has displayed a turbulent flow initially, followed by a laminar flow. The river bank is commonly occupied by big boulders and the varying size of emergent rocks, which have not been flooded even during the rainy season when water levels rose to the maximum level, thereby creating a space for deposition of sand, silt, degraded liter as well as pebbles. In addition, the water spray from turbulent flow of the river had created a mist that had fumigated the place with moisture. The so-called "*Quercus* Woodland" community in this area is dominated by the *Quercus glauca* Thunb. and associated with *Lindera bootanica* Meisn.; *Bauhinia purpurea* L. and *Schima wallichii* (DC.) Korth (Figure 3 and 4A).

4. Discussion and Conclusions

4.1 Floristic composition

A total of 172 species were recorded in the present study. This reflected a plant diversity of the riparian vegetation along the river and also the flooded banks of the Sherichhu River, which represents a river of the lower montane in the Eastern Himalayan area (Table. 2). The most diverse family in the present study were Fabaceae (18 species), followed by Rubiaceae (10 species), Malvaceae (8 species), Cyperaceae (8 species), and Orchidaceae (6 species), respectively.

Species of the plants recorded from the Sherichhu River could be categorized according to their position relative to the bank of the river due to different water levels as well as their adaptation to stand against different degrees of water current. However, it has to be noted that no submergent aquatic plant species has been recorded in the present study. This might be due to the fact that the water velocity of the river in the study area is strong all the year round. Therefore, the bottom of the river is composed mostly of rolling pebbles and coarse sand. This situation could be burdensome for establishment of any submergent plant species. In spite of that, many plant species performing rheophyte characteristics have been recorded along the river banks, which were sometimes flooded (van Steenis, 1981). Considering plant species (terrestrial plants only and not included lianas;

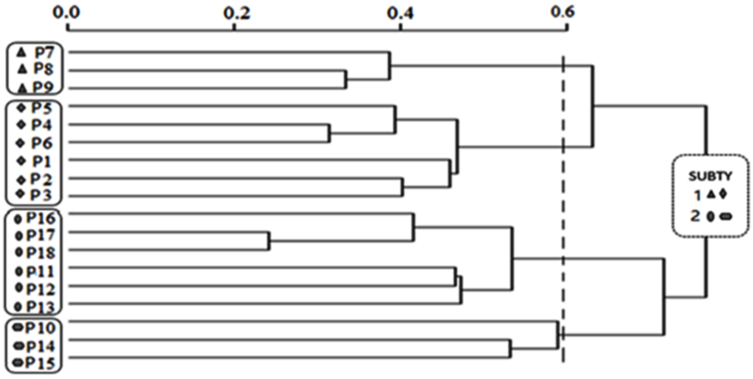

Figure 3. Cluster analysis dendrogram based on species composition (scale indicates the similarity percentage among the study plots).

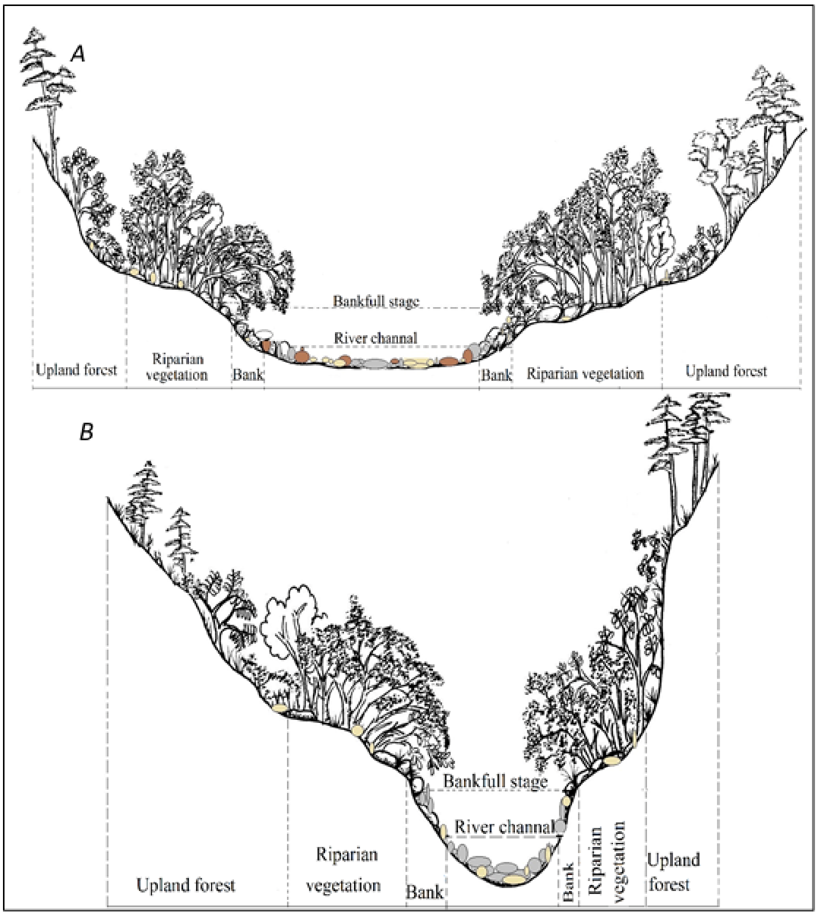

Figure 4. Schematic cross section vegetation profile of the riparian vegetation along the Sherichhu River within the study areas: A; U shaped and B; V shaped valley.

climber as well as epiphytes) that occurred along the river banks, and which perform "rheophyte" characteristics following three classes might be separated due to the degree of tolerance to running water of the fast-flowing river:

1) Rheophytes: This is a group of plants, which adapts in order to accommodate the velocity of the water current, especially, in the flood season when the level of water is high and they, therefore, have to stand not only the submerge conditions in the flood season when the water level in the river rises, but also its strong current velocity for a period of time. In the present study, these species were recorded only in areas where the water rose up and flooded in late spring/early summer. Therefore, this habitat becomes aquatic with strong velocity current and is not found anywhere else. Such plant species have some common rheophyte characters (van Steenis, 1981) of decumbent or creeping habit with long

Table 2. Similarities and dissimilarities between plots using Sorensen coefficient index.

Study Plot	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18
																		Dissimilarities
P1		0.46	0.46	0.38	0.48	0.52	0.55	0.54	0.66	0.81	0.75	0.77	0.72	0.82	0.69	0.75	0.86	0.79
P2	0.54		0.40	0.36	0.56	0.44	0.59	0.70	0.80	0.76	0.79	0.79	0.79	0.83	0.84	0.85	0.87	0.83
P3	0.54	0.60		0.46	0.54	0.48	0.61	0.69	0.81	0.80	0.77	0.77	0.71	0.81	0.82	0.76	0.81	0.79
P4	0.62	0.64	0.54		0.35	0.31	0.60	0.62	0.75	0.73	0.76	0.79	0.79	0.81	0.75	0.79	**0.89**	0.81
P5	0.52	0.45	0.47	0.65		0.43	0.48	0.54	0.68	0.75	0.79	0.84	0.71	0.86	0.71	0.76	**0.89**	0.85
P6	0.48	0.56	0.53	0.69	0.57		0.49	0.57	0.70	0.71	0.80	0.75	0.65	0.75	0.73	0.75	0.79	0.74
P7	0.45	0.41	0.39	0.40	0.52	0.51		0.38	0.39	0.65	0.74	0.79	0.65	0.76	0.71	0.71	0.80	0.75
P8	0.46	0.30	0.31	0.38	0.46	0.43	0.62		0.33	0.73	0.70	0.79	0.64	0.77	0.72	0.72	0.78	0.79
P9	0.34	0.20	0.19	0.25	0.32	0.30	0.61	0.67		0.69	0.62	0.76	0.66	0.76	0.68	0.67	0.79	0.77
P10	0.19	0.24	0.20	0.27	0.25	0.29	0.35	0.27	0.31		0.67	0.77	0.69	0.63	0.54	0.74	0.86	0.79
P11	0.25	0.21	0.23	0.25	0.21	0.20	0.26	0.30	0.38	0.33		0.47	0.47	0.73	0.69	0.62	0.54	0.56
P12	0.23	0.21	0.23	0.21	0.16	0.25	0.21	0.21	0.24	0.23	0.53		0.48	0.69	0.73	0.52	0.51	0.55
P13	0.28	0.21	0.29	0.21	0.29	0.35	0.35	0.36	0.34	0.32	0.53	0.52		0.64	0.65	0.52	0.43	0.45
P14	0.18	0.17	0.19	0.19	0.14	0.25	0.24	0.23	0.24	0.37	0.27	0.31	0.36		0.53	0.59	0.72	0.72
P15	0.31	0.16	0.18	0.25	0.29	0.27	0.29	0.28	0.32	0.46	0.31	0.27	0.35	0.48		0.58	0.78	0.75
P16	0.25	0.15	0.24	0.21	0.24	0.25	0.29	0.28	0.33	0.26	0.38	0.48	0.48	0.41	0.42		0.34	0.44
P17	0.14	0.13	0.19	**0.11**	**0.11**	0.21	0.20	0.22	0.21	0.14	0.46	0.49	0.57	0.28	0.23	0.66		**0.24**
P18	0.21	0.17	0.21	0.19	0.15	0.26	0.25	0.22	0.23	0.21	0.44	0.45	0.55	0.28	0.25	0.56	**0.76**	
Similarities																		

linear and/or linear-lanceolate leaf that flow along the strong water current and not against it. Moreover, their root system and/or the rhizome are net-like structures that penetrate under the coarse sand/pebbles along the flooded river banks or suspending on the river rocks firmly. These plant species were recorded for the whole selected study areas along the river (Table 1). They are mostly herbs and shrubs, e.g. Monilophyte herbs: *Equisetum hyemale* and *Nephrolepis cordifolia*. Monocot herbs: *Fimbristylis littoralis*, *Eleusine indica*, *Pseudechinolaena polypostachya,* and *Pogonatherum paniceum.* Shrubs: Eudicots; *Rhus panicu-lata*, *Flemingia macrophylla*, *Desmodium elegans*, *Ficus squamosa* and *Rumex nepalensis* (Table 1).

In addition, some tree/shrubby tree elements could be seen along the edge of the river bank. With a tree or shrubby tree habit their root systems might have been adapted to stand the strong velocity current of the fast-flowing stream as these are rheophytes as well; such species could be seen from plots 1-10 where the river is small and fast-flowing in a "V-shaped" valley but not in a "U-shaped" valleys, e.g. *Wrightia arborea*, *Aralia foliolosa*, *Duabanga grandiflora,* and others (Table 1).

2) Flood tolerant species: These are plants species that occur on periodically inundated places caused by the mass of water that flow down, due to melting snow from high mountain peaks. This caused inundating conditions in small plain areas within the "U-shaped" valleys. These inundate conditions for a period of time in a year by the river led to sedimentation, thus creating the small alluvial plain. Plants that occurred in such areas have to stand not only the inun-dating conditions, but also the strong velocity of the water current that runs down as well. There are many plant species which could be recognized in plot 11-18 (Table 1) that lay along the river bank in the "U-shaped" valley of the river. In any case, such elements could be detected in plots 9-10 which are laid in a connective part of the river from a "V-shaped" to a "U-shaped" valley (Figure 2; 4A and 4B; Table 1). Such elements act as a marking of the edge of the highest level of the river: Tree elements: *Mallotus philippensis*, *Muraya koenigii*, *Syzygium venosum,* etc.; Shrub elements: *Solanum viarum*, *Caesalpinia decapetala,* etc. Otherwise, species composition of the plants in the small flooded areas have been recorded in plots 11-18 and dominated by tree elements (Table 1), e.g. *Quercus glauca*. *Radermachera sinica*, *Grewia sepiaria*, and shrub elements (Table 1), e.g. *Saurauia roxburghii*, *Saurauia napaulensis*; *Matelea carolinensis*, *Vaccinium vacciniaceum*, *Citrus medica,* etc.

3) Terrestrial herbaceous plant elements: Terrestrial elements in this aspect are those plant species that occur only a short period of time only in the dry season, mostly in summer or late summer. They are either annual or perennial herbs. For the latter, only underground parts would be left in the flooded season, when there is mass flow of water in early spring after the melting of snow in high mountain peaks. Many herbs, especially, the annual ones would come up. However, the herbaceous composition along the river bank in the area of "V-shaped" and "U-shaped" valleys were different. This might be due to influences of environmental factors, especially, light (more open in the "V-shaped" valley) and litter (more litter accumulation in the "U-shaped valley) (Figure 4). Herbaceous plant compositions in these two distinct topographic types of the river are, therefore, different (Table 1): i.e. for the "V-shaped" valley, e.g. *Baleria cristata*, *Inula cappa*, *Bidens bipinata*, *Crotalaria sessiliflora*,

Desmodium laxum, etc. Concerning the "U-shaped" valley, the herbaceous community that has been recorded is composed mostly of shade and litter preferring species, e.g. *Bidens pilosa*, *Euphorbia hirta*, *Chassalia curviflora*, *Ophiorhiza fasiculata*, *Galium elegans,* etc. In any case, perennial herbs mostly belong to the monilophytes as seen along the river banks when the water levels of the rivers decreased in mid-summer. However, the weather was not really dry as moist habitat plants species were recorded, e.g. *Adiantum lanulatum*, *Asplenium pteropus, Nephrolepis cordifolia, etc.*

4.2 Plant communities, structure versus landscape of the Sherichhu River valley

Considering the four plant communities according to the species composition revealed by the cluster analysis (Figure 3) as well as the similarities and dissimilarities between plots using Sørensen coefficient index i.e. the *Mallotus-Desmodium-Rhus* shrubland (plot 1-6; Table 1); the *Syzygium venosum* woodland (plots 7-9; Table 1); the *Albizia-Flueggea* woodland (plot 10, 14, and 15; Table 1), and the *Quercus glauca* woodland (plot 11-13, and 16-18; Table 1), together with the valley-landscape of the Sherichhu River could suggest that the *Syzygium venosum* woodland and the *Mallotus-Desmodium-Rhus* shrubland occurred along the river in the so-called "V-shaped" valley (Figure 2C, D, E and 4B). It has indicated that all plots of both plant community types have a close relationship and, therefore, belong to a given type of plant community. This plant community type occurred along the river where no sedimentation/accumulation of soil had taken place as the river is running in the defile between two steep sides of the gorge in the "V-shaped" valley as there is no flat plain for alluvial sedimentation to occur. The river could come up to a certain level in early spring/rainy season to late summer due to a large amount of water from melting snow at the high peaks of the Himalaya or from regular rain in the rainy season (June-August). Therefore, the most common elements along this fast running part of the river are those rheophytes, which stand the strong velocity of the water current (see also the former topic). In any case, in the upper part of the "V-shaped" valley there are some parts of the strands where the defile would gradually extend and there are big boulders and space enough for tree species to establish. Therefore, the *Mallotus-Desmodium-Rhus* shrubland has been substituted gradually by the *Syzygium venosum* woodland. On the other hand, regarding the upper areas of the river, the valley here is wider in the so-called "U-shaped" valley with some plain in the defile as this is the character of lower Himalayan areas. The flooded plains, mostly seen inside of river curves are nevertheless enough to let alluvial sedimentation to occur. Therefore, in such places, different types of plant communities were established, i.e. *Quercus glauca* woodland and the *Albizia-Flueggea* woodland (Figure 2A, B, E; 3 and 4A). It is to be noticed that both types of plant communities are woodland as they developed on these small alluvial flood-plains that, in general, are rich with nutrients.

The cluster analysis as well as Sørensen similarities coefficient index also implied that the *Quercus glauca* woodland is more related to the two types of plant community in the "V-shaped" valley than the *Albizia-Flueggea* woodland, which is separated from each other. Due to the fact that both types of plant community occurred in the same physical environment type of the "U-shaped" valley as well as the fact that this *Albizia-Flueggea* woodland occurred within the range of the *Quercus glauca* woodland randomly (plots 10, 14-15 of the former within the range of the plots 11-16 of the latter), it might be suggested that the plant elements in the *Albizia-Flueggea* woodland might be those pioneer species in the secondary state condition. The *Quercus glauca* woodland has been disturbed by many means of anthropogenic influences such as agriculture as the habitat is supposed to be appropriate among the difficult access mountainous areas for human settlement. Owing to the cluster analysis and Sørensen similarities coefficient index, it also pointed out close similarity of the *Albizia-Flueggea* woodland to the *Quercus glauca* woodland, however, with less diversity (Figure 3 and 4A; Table 2).

4.3 Environmental impact on the species composition

The canonical correspondence analysis (CCA) analysis (Figure 5) suggested that some selected environmental variables (altitudes, aspect, slope, and litter thickness) had an impact on the vegetation composition. Variables showed 40% of the total variation in the species composition data can be explained by four canonical axes. Eigenvalues for four constrained axes of CCA were 0.5234, 0.1746, 0.1054, and 0.0959, that revealed 52%, 17%, 10%, and 9% variation on the axes CCA1, CCA2, CCA3, and CCA4, respectively ($P < 0.001$).

Among the four environmental factors, the altitude had performed 51.28% of the total variation in the species composition data that can be explained by canonical axis I ($P<0.001$) (Figure 5), indicating that altitude is an influential factor for the community composition. Though the altitude itself might not have a direct impact, however, it may have indirect impacts on the humidity (higher altitude with less humidity) as well as the temperature or other factors. As illustrated by Thapa *et al.* (2016) the *Quercus* dominated plant community located in the lower montane vegetation is unique in terms of species composition and structure. The *Quercus glauca* woodland community in the riparian vegetation is also characteristic more than other communities. Some given species in this study, e.g. *Chirita bifolia*, *Aeschynanthus parviflorus*, *Persicaria nepalensis* and *Schoenorchis gemmata* were associated with *Quercus glauca* at higher altitudes (Figure 5). Likewise, such species, e.g. *Osyris lanceolata*; *Euphorbia hirta*, *Desmodium elegans*, *Abrus precatorius*, and others are recognized as components of lower altitude plant communities (*Mallotus-Desmodium* and *Rhus* dominated

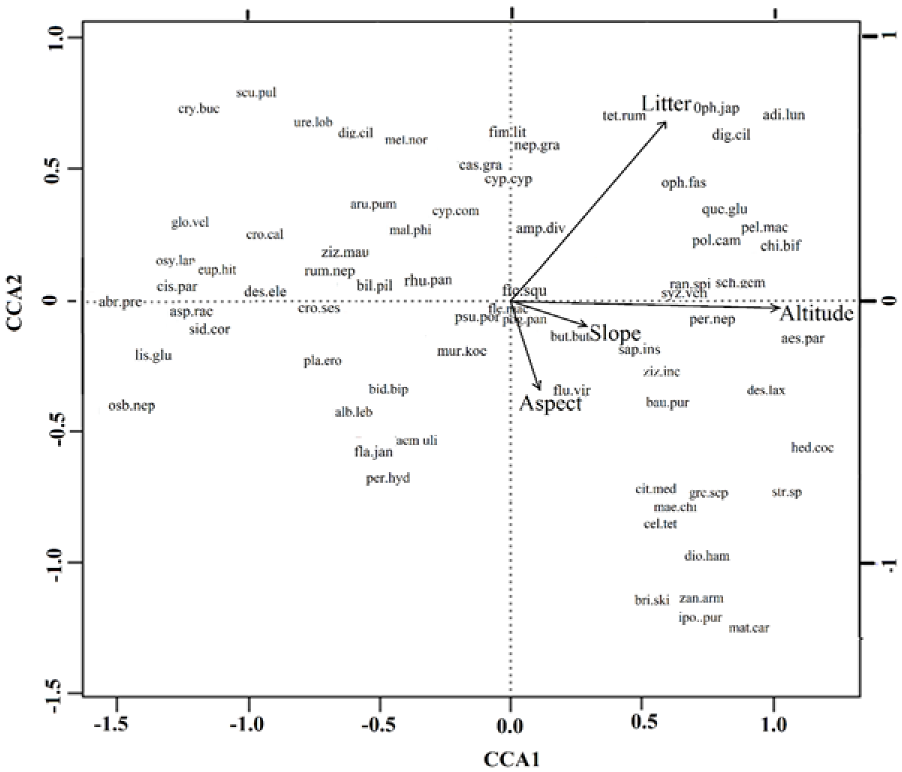

Figure 5. Canonical correspondence analysis ordination of species composition and environmental variables in the riparian vegetation of Sherichhu River. Along the elevation gradient (left to right), altitude and litter depth increase gradually. Distributions of species on the ordination map is related to environmental gradient and litter thickness. Species such as *Chirita bifolia* D. Don.; *Aeschynanthus parviflorus* (D. Don) Spreng.; *Desmodium laxum* DC and *Schoenorchis gemmata* (Lindl.) J.J. Sm. are elements of the plant communities accommodated within U-shaped valley while the species such as *Abrus precatorius* L.; *Asparagus racemosus* Willd.; *Litsea glutinosa* (Lour.) C.B.Rob.; *Cissampelos pareira* L. and *Osyris lanceolata* Hochst. & Steud. are elements of the communities situated in V-shaped valley (full names and authors of each species are given in Table 1).

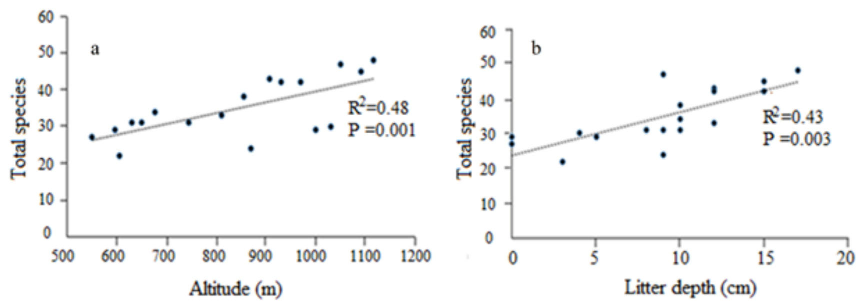

Figure 6. Relationship between; a: altitude and species richness; b: litter depth and species richness.

shrublands). The regression analysis also supported the CCA results, i.e. the number of species (species richness) is found to be increased along the altitude range of the current study site (Figure 6).

Moreover, the litter thickness was a determining factor for the plant species composition as well. It explained 32% of the total variation in a species composition data set, which could be explained by the canonical axis I ($P<0.003$) (Figure 5). The regression analysis also indicated that the species richness was positively correlated with the litter thickness ($R^2 = 0.43$, $P<0.003$) (Figure 6). This could be due to the rate of decomposition of the litter was faster as the environment was moist owing to the regular foggy spray from the fast flowing river as well as the shade condition of the dense vegetation canopy. This might help in the increasing the thermal amplitude in the soil, hence, promoted the microbiological activity, thereby performing as a driving factor of nutrient production for plants and seedling as suggested by Koller *et al.* (2013). Supplementary reasons could be that the emergence of the seedling might not depend on the litter thickness or less compact litter would have no impact on their emergence, e.g., *Tetrastigma rumicispermum*, *Ophiopogon japonicas*, *Adiantum lunulatum*, etc., positively correlated with the litter thickness, whereas species, such as *Bidens pilosa*; *Albizia lucidior* and *Persicaria hydropiper* etc., were negatively correlated with the litter thickness, showing their adaptability in the variable nutrients (Figure 5). It could be suggested that the litter accumulation plays a significant role in the species composition and community determination along the riparian vegetation in the Sherichhu River base. This is supported by a former study on the riparian vegetation (Loydi *et al.*, 2014). However, more investigations are needed to find further effects of the altitude and litter thickness on other variables.

Riparian vegetation is not only important in terms of its high biodiversity, but also due to the fact that it helps in protection of both banks of the river. Various human activities have altered and modified the riparian vegetation along the river in this area of the Himalayan range. Unless the remaining riparian vegetation are systematically studied beforehand and protected by laws, the natural riparian vegetation might gradually wipe out in the future.

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