PHYTO-ECOLOGICAL ASSESSMENT OF MAHAKALI RIVER, FAR-WESTERN NEPAL

RIPU M. KUNWAR[1] ✉, PRATISTHA PYAKUREL[2], CHUNDAMANI BURLAKOTI [3], PARAKRAM PYAKUREL[4] AND SHREE G. SHAH[5]

[1]Department of Geosciences, Florida Atlantic University, USA
[2]Energy for Development Nepal, Kathmandu, Nepal
[3]Ottawa, Ontario, Canada
[4]Department of Engineering, Florida Atlantic University, USA
[5]Erma Nepal, Kathmandu, Nepal
**Corresponding author: rkunwar@fau.edu*

ABSTRACT

An assessment of phyto-ecology and socio-economy of wetlands of Mahakali River system of far-western Nepal was carried through rapid ecological assessments, participatory discussions, transects and quadrat studies, and laboratory analyses to reveal the interactions between physico-chemical characteristics of water and soil, biodiversity and socio-economic regimes. Mahakali river system was flanked by a number of tributaries, steep cliffs, rocks, and was closely associated with riverine and mixed *Shorea robusta* (Sal) forests, resulting in richness and diversity of habitats and plant species. Vegetation succession was found to conspicuous as transcends farther from river edge, the *Phragmites karka* was gradually succeeded by *Saccharum spontaneum* and riverine forest species such as *Acacia catechu, Dalbergia sissoo, Bombax ceiba, Eugenia jambolina*, *Aegle marmelos,* etc. A total 140 plant species including 78 ethnomedicinal were inventoried, representing about 27 percent of the district flora. This study serves as a baseline data of phyto-ecological attributes of Mahakali River and can be taken as a reference to investigate the temporal changes in Mahakali River system.

Keywords: wetlands, Mahakali River, macrophytes, riverine forest, socio-economy

INTRODUCTION

Since about 6% of total global land area coverage (Turner, 1991), wetlands constitute about 7,437 km^2 or approximately 5.3% of total area of Nepal (Bhandari*,* 1993) with maximum coverage (38%) from far-western Nepal (Bhandari, 1996). These wetlands as followed to Rajbanshi and Gurung (1994) are categorised into rivers (53%), lakes (0.7%), reservoirs (0.2%), ponds (0.7%), marshes (1.6%) and deep-water agricultural lands (44%), etc. for easier interpretation. Later, two additional types of wetlands namely flood plains and swamps were accounted by Sah in 1997. However, Nepal's extensive wetlands lie as a vast and possesses varied riverine floodplains and wetlands formed by the four major rivers (Gandaki, Koshi, Karnali, and Mahakali) that emerge from the Himalayas (Mool *et al.,* 2001). Since the far-western Nepal and Mahakali river system are worth for further research because they both constitute the credentials in national wetland coverage and distribution.

Wetland is the land where water level is at near or above the land surface covered by shallow water enough to enhance soils and lives (Cowardin *et al.,* 1979). It literally means *Simsar* in

Nepali where *Sim* is a derivative of the Persian word (*Sih* - low grade land unfit for cultivation) and *Sar* is Sanskrit word meaning water. Therefore *Simsar* is known as land with water. These landscapes are amongst the first few areas where both agriculture and human civilization had begun and record of human civilization intimately linked with wetlands dated back to about 4,500 BC (Roach, 2015). In ecological terms, it is an ecotone referring to the transitional zone between terrestrial and aquatic communities (Senft, 2009), and this study followed the ecological definitions.

Wetlands are often considered as the most productive ecosystem and important natural resource for economic and developmental sustainability (Kaul, 2003). They possess a number of functional, economic and aesthetic values and are considered as multitude of services, sinks, stimulators and stabilizers and hence coined as nature's kidney (James, 1995; Poddar *et al.*, 2001). Nepalese wetlands harbour 42 globally threatened species (CSUWN, 2009) with over 25% of the country's total 6,653 flowering plants (Kunwar *et al.,* 2010). Furthermore, over 180 species of fishes, 190 water dependent birds and several other endangered animals are inhabited (Bhandari, 2009). However the quality, quantity and size of the wetlands are gradually being declined due to eutrophication. Escalating human onslaughts: habitat loss, agricultural run-off, drainage and overexploitation of resources base led to reduce the area of wetlands thereby, endangering various biological resources. Though the wetlands possess a number of values, services and products, they are not in an essence of primary assessment (Poudel, 2009).

MATERIALS AND METHODS

Study sites

Field visits were made in 26 sites of three districts Baitadi, Dadeldhura and Darchula within May-June and December 2006. The sites stretch within 29° 18' 51" to 29° 03' 49" N latitude and 80° 15' 0.64" to 80°35' 33" E longitude and 1019 ft. to 6247 ft. altitude. For quantitative assessment (richness, diversity and abundance) of wetland flora, nine different sites (Lali and Gokule of Darchula; Binayak, Pancheswor and Dharmagad of Baitadi; and Rupal, Sirse, Parsuram and Chandani of Dadeldhura districts) were selected (fig.1a & b). The sites were selected based on consents from local communities and stakeholders.

Rapid assessment and participatory rural appraisal were basic modes of primary data collection. Local communities were consulted for study of indigenous resource management and usage of the locally available plants. Checklist were prepared and discussed to the key persons to crosscheck and verify the information for assessing the threat and conservation status of wetland plant communities. Threat category of CITES, IUCN, CAMP and HMGN, etc were consulted and triangulated with field level data to assign the conservation assessment. Secondary literatures: reports and articles related to Mahakali wetland system and study districts were reviewed.

Stratified random sampling method along several transects with the help of a 1m x 1m quadrat (Zobel *et al.,* 1987) was adopted and measured to analyse the quantitative assessment. The length of transects and number of quadrats in each transect within each sampling site adjusted according to the depth of littoral zone and physiography. Transect study was carried out by plotting perpendicular transect from centre of water body covering perennial zone, seasonal zone, marshy zone to terrestrial zone (forest). Abundance of aquatic plants in water body, marshy zone

and terrestrial zone was estimated for each species according to Kohler index (KI), following a five level scale: A = rare, B = occasional, C = frequent, D = abundant and E = very abundant/ dominant (Kohler, 1978).

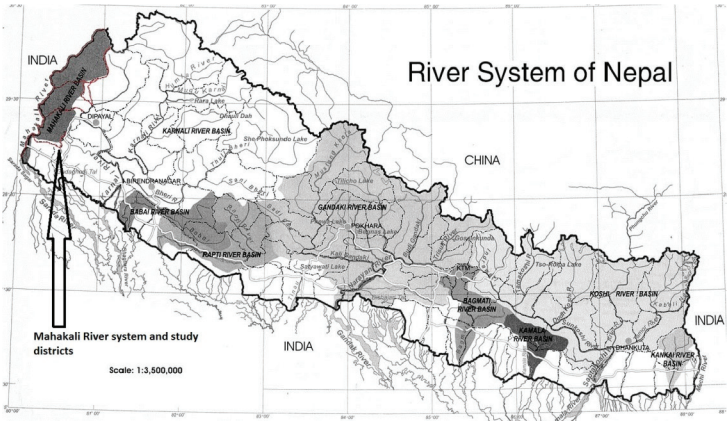

FIG. 1A. River system of Nepal (Shrestha, 2012).

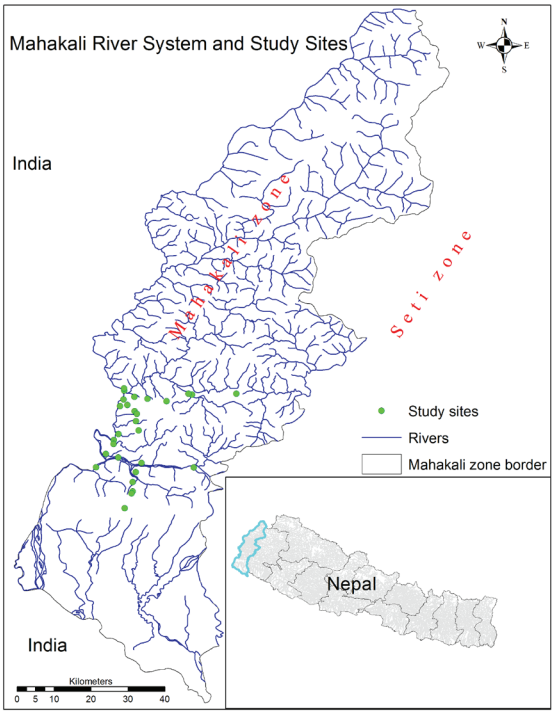

FIG.1B. Study sites.

Records were also taken on presence or absence (frequency) of species cataloguing the growth-forms: submerged, floating, emergent-upper littoral, marshy vegetation, terrestrial shrubs and trees at 1 m interval following Sah (1997) and Shrestha (2000). Specimens were identified with the help of literatures (Khan & Halim, 1987; Cook, 1996; Press *et al.,* 2000; Bhandari, 1993, 1996). Water sample collection and preservation was made following Zobel *et al.* (1987). A 200 ml water sample was collected at each site and preserved in Lugol's solution for phytoplankton identification following Trivedi & Goel (1986). Trees and shrubs were quantified with the rapid assessment and observation methods. Other associated vegetation were quantified with the help of quadrat by hand picking method. Diversity indices were computed following Shannon-Weiner (1963). Index of similarity of different life forms between above and below Pancheswor, Baitadi was calculated. Water quality and soil analysis was made and their relationship with wetland and vegetation was assessed. Data analysis was carried out in Microsoft Excel and Minitab 17.

RESULTS AND DISCUSSION

Mahakali wetland system

The Mahakali river system (29° 25' and 29° 47' N latitude and 79° 55' and 80° 35' E longitude), characterising enormous scope of electricity and irrigation, borders Nepal and India. The Pancheswor Multipurpose Project (PMP), a bi-national water development scheme based on Mahakali river resource aims at producing energy and water for irrigation for bordering habitats of the Nepal and India with constructing a Pancheswor high dam, a Rupali gad re-regulating dam and a Poornagiri re-regulating dam. The scheme covers parts of Darchula, Baitadi, Dadeldhura, Kanchanpur districts of Nepal. Many sub-wetlands furnish the Mahakali and constitute wide scope of ecology and economy (table 1).

TABLE 1. Sub-wetland systems of Mahakali River.

Site	District	Area (ha)
Pancheswor, Dharma gad	Baitadi	3107.67
Rupali gad	Baitadi	4058.00
Chadani-Poornagiri	Dadeldhura-Kanchanpur	4699.88
Chameliya	Darchula	1582.08 (River length 5446.36 m)
Garma gad	Baitadi	80.42 (River length 404.86 m)
Surnaya gad	Baitadi	828.50 (River length 4790.38 m)
Rupali gad	Baitadi	47.09 (River length 322.49 m)
Sirse gad	Dadeldhura	368.85 (River length 86536.14 m)
Rangun khola	Dadeldhura	49.75 (River length 2285.11 m)

Associated habitats

The headwater of Mahakali mainstream originates from the glaciers at an elevation of 3000 m (HMGN, 1991) and it is structured by many seasonal streams, tributaries and small rivers. Although the wetlands originating from high Himalayas or middle mountains are associated with large flood plains, the Mahakali does not support this and comprises limited flood plains. Major habitat types of Mahakali are fast flowing river (C-Con and Cowel International, 1994), backwater, tributaries, streams, inlet brooks, flood plains, swamps, marshes, pebbles, sandbars, etc. Backwater portions are prominent in the mouth of feeder inlets, shallow and stagnant water bodies, characterized with high phytoplankton biomass (JICA/New Era, 2000). Associated rivers and tributaries of the Mahakali River are Uku, Radam, Chamelia, Sadan, Samania, Rupali, Buwa, Bali, Sarmali, Katela, Sirse, Puntura, Marthani, Ujelighat, Rangun, Kuna, Chaalte, Bas, Dhakne, Hatwani, Karali, Dharmadwar khola etc. Of the tributaries, Chameliya and Rangoon are major ones contributing sufficient and continuous inflow to the main system. The associates: Lali khola, Chameliya khola, etc. possess high transparency and temperature (table 2).

TABLE 2. Mahakali wetland types.

Wetland habitat	Area (ha)	Wetland habitat	Area (ha)
Sand, flood plain	7602.60	Pond	38.91
Glacier	3039.36	Swamp	14.41
Water body, river	1822.55	Lake	12.18

The confluences of Mahakali river with Lali khola at Gaje gada, Lali; with Chameliya khola at Sera; and with Chaudali khola at Binayak, and of Panjunaya khola and Chameliya khola at Sirse have formed extensive large flood plains. Chameliya/Chaulani is relatively fast flowing and creates extensive floodplains featuring sand bars, gravels, and large boulders and gorges. Mahakali is relatively fast flowing river flanked by sandy gravel beds on both side followed by shrub lands and forest lands. It is intervened by wild steep cliffs and rocks. Greater parts of Mahakali River and its associates are remote and inaccessible. Because of the high water velocity devoid of submerged and floating hydrophytes is prevalent. The downstream of Mahakali comprises slow flowing secondary channels, backwater, floodplains, swamp, marshes, boulders/rocks and sandbars. Slow flowing channels characterize with low transparency and high sedimentation at lower belts whereas some rapids are common at the places where gradient is very steppe. This implies considerably low nutrient level at the existing condition and there exist no problem of algal bloom. The low level of nutrient/plankton notes on formation of backwater pool during sampling periods. The portions with shallow depth, stagnant low turbidity and having nutrient enriched inlets and shorelines record higher species diversity. The stagnant and slow flowing water bodies have warmer temperature compared to main-river and provide natural habitat for the growth of submerged macrophytes.

Physico-chemical properties

The associates of Mahakali greatly alter water quality and temperature of the main river system with featuring very low transparency, high sedimentation and low velocity. Water acidity increases as descending downstream (R^2 = 82.3%) (fig.2). Maximum water pH (7.7) was recorded in Lali khola-Mahakali confluence, Darchula district followed by pH 7.6 in Chameliya River at close downstream. Minimum pH (6.5) was noted in Rangun-Mahakali confluence, Dadeldhura district (table 3). However, the maximum pH 8.8 and Dissolved Oxygen 5.0 were noted from Pancheswor, Baitadi in earlier reports (CBS, 1998; DHM, 1999; CBS 2013). In present study, average water pH and Dissolved Oxygen of Mahakali were 7.2 and 4.8 mg/l respectively.

Water turbidity and pH were higher in Mahakali river system and lower in associated tributaries. It was noted that tributaries entering the main Mahakali river system bring coarse sediment while the soil erosion and mass wasting in Mahakali River along the banks bring the fine sediment into the river. The stagnant and slow flowing water bodies were warmer and contributed as favorable habitat for the growth of submerged macrophytes. Nutrient enrichment is most in reservoirs or in slow flowing water bodies that lead growing of algae and other aquatic plants. The backwater portions are prominent at low velocity zones where water temperature is high. Weedy species were abundant and they are likely to spread rapidly in higher temperature conditions. Riverine grasslands are considered as highly productive among other wetland types and it was attributed to the alluvial soils and high year round soil moisture availability (Lehmkuhl, 1989). Wet grasslands would create more scopes of wildlife diversity and richness by providing shelters, food and nutrients.

Vegetation

The plant communities gradually change (species number increase by R^2 = 0.8%) as changing the sites from a more typical hydric wetland to transitional due to decrease in soil wetness along the gradient between flooded and dry areas. The wetland habitats of Mahakali river system and intersecting tributaries were relatively undisturbed and enriched with aquatic plant species, however their richness is weak due to higher gradient upstream and high velocity water current. Water and moisture dependent plants were found to be decreasing (R2 = 47.9%) as increasing elevation and this could be attributed to the less area coverage by wetlands in higher elevations. High rate of water inflow and outflow and limited shallow areas along the shorelines often preclude aquatic macrophytes growth (Cook, 1996). Backwaters are prominent at low velocity zones where water temperature is high. Pool areas and tributaries with higher temperature conditions are enriched with floral and faunal species (HMGN, 1991) and luxuriant growth of planktons and weedy species was prominent in backwaters and tributaries. A rise in temperature accelerates chemical reactions, reduces solubility of gases, amplifies taste and odor and elevates metabolic activity (Usharani *et al.*, 2010).

Plant species composition

Altogether 140 species of wetland plant species including 41 common species were reported from the Mahakali wetland. Index of similarity was the highest for phytoplanktons (90.90%). The richness and diversity of plant communities in wetlands depends on wetness of soil, water current

and temperature. Alien invasive species, *Eupatorium odoratum, Parthenium hysterophorus, Ageratum conyzoides*, *Lantana camara*, etc. were frequent at roadsides, transition areas, flood plains and backwaters. Other species such as *Myriophyllum aquaricum* (Amalpate jhar)*, Mimosa pudica* (Lajjawati)*, Leersia hexandra* (Karaunte jhar)*, Ipomoea carnea* (Besram)*, Alternanthera philoxeroides* (Jaljambhi)*,* etc. are invasive aliens (Bhandari, 2009).

Phytoplanktons - A large population of phytoplanktons was recorded from backwater and pool areas, supports a growing population of zooplanktons, which in turn supports carnivorous fish population. High phytoplankton biomass was revealed in backwaters. The inlets (inoculums) (JICA/New Era, 2000) account of low velocity were rich in algae and macrophytes. The shoreline vegetation, a major source of organic nutrients and mineral washout (Gronlund, 2012) enhances phytoplankton biomass. Richness of phytoplankton was also obvious in rainy and summer season. There were 20 species of floating species and among them *Azolla pinnata, Lemna* species, *Nitella* species, *Spirodella* species, etc. are common floating.

Algae - The dominant algae species in study area were *Spirogyra* species, *Rivularia* species, *Zygnema* species and *Stigoclonium* species. The frequent *Spirogyra, Cladophora* and *Ulothrix* species form the thick blanket growth and colonized balls and increase the nutrient level in water. Marshes and swamps are rich in *Chara* species, *Ceratophyllum* species, *Vallisnaria* species, *Potamogeton* species, etc. *Hydrilla, Chara, Vallisneria, Potamegeton species* of algae are major submergant. There were altogether nine species of algae as submergant. These species complement the niche for fish spawning. *Chara* alga species are conducive to egg laying environment for aquatic snails, mussels and frogs. Alga and some aquatic ferns and weeds (*Azolla*, *Lemnids*, *Potamogeton* and *Vallisneria* species) are reported to be used as food for ducks, geese, Rhino, and a habitat for aquatic snail sand frogs (BPP, 1995) and small fishes and water birds.

Macrophytes - Richness of macrophytes attained the highest at low current velocity (Hrivnak *et al.,* 2007). The aquatic macrophytes have low resistance to water currents and were therefore usually found only in shallow areas, flood plains and marshes (HPC, 1989). There were 18 major emergent species and shoreline emergent such as *Arundo, Phragmites, Saccharum* etc. reduce the force of water waves and help to prevent shoreline erosion whereas sub-emergent species (*Hydrilla, Chara, Vallisneria* etc.) weaken the wave action and help stabilise bottom sediments.

Altitude, distance to source and drainage, hydrological regimes, etc. are considerable attributes for macrophytes richness (Cortes *et al.,* 2008). Marshes do not dry up even in summer and thus create swampy land where dominance of *Alternanthera sessilis, Barleria cristata, Cyathocline purpurea, Cyperus species, Desmodium triflorum, Eclipta prostrata, Equisetum species, Euphorbia hirta, Hedyotis corymbosa, Justicia procumbens, Kyllinga nemoralis, Paspalum distichum, Phyllanthus amarus, Saccharum spontaneum*, etc. was seen. Marshy grasses like *Arundo, Eulaliopsis, Phragmites, Juncus species* were also common in flood plains. A total of 22 marshy species and maximum 72 terrestrial species were recorded from the closet of Mahakali wetland. The common shoreline macrophytes were *Saccharum spontaneum*, *Equisetum debile*, *Ipomoea carnea*, *Persicaria hydropiper*, *Cyperus igitatus*, etc. *Ipomoea carnea, Alternanthera sessilis, Saccharum spontaneum* and *Phragmites karka*

were abundant and weedy in nature. *Themeda arundinacea* associated with *Narenga* species, *Imperata cylindrica*, *Saccharum spontaneum*, *Saccharum bengalense* was common. Species and associations: *Typha elephantiana, Phragmites karka, P. karka - S. spontaneum, P. karka – S. spontaneum – S. arundinaceum, S. spontaneum, I. cylindrica, Themeda arundinaceum, Narenga porphyrocoma, I. cylindrica – N. porphyrocoma* etc. were also reported from Mahakali wetlands (Peet *et al.,* 1999).

In water logged areas *Saccharum-Phragmites* association forms an intermediate community in a course of succession (Dabadghao & Shankarnarayan, 1973). *S. spontaneum* and its association *Saccharum-Tamarix* were observed as pioneer successor and similar account was revealed by Dinerstein (1979), Lehmkuhl (1989). *Phragmites karka* is very tall jointed grass that grows in thick pure stands on swampy lands. It is up to 5m tall and its stem diameter is 2-3cm. It is an indicator of clean fresh water. It is a good fodder of buffaloes thus it's patch could be an important habitat of the globally threatened Wild buffalo (*Bubalus bubalis*.)

As one goes farther from water edge, the *P. karka* community is gradually replaced by marshes species (*Sphenoplectus* species*, Ipomoea* species, etc.) and *S. spontaneum* community at distant end. The *Saccharum* patches merge to the forests depending on the slope. *S. spontaneum* are short and more prostrate where the flood water remains deep for longer whereas they are taller in drying area. *S. spontaneum* and *P. karka* were dominant in Mahakali and were important for Rhinoceros, Hog deer, Tiger (Laurie, 1978; JICA/New Era, 2000), Wild elephant (Sukumar, 1989) because *Saccharum* and *Phragmites* species were mixed with riverine deciduous forest species (Sah, 1993) *Dalbergia sissoo, Acacia catechu, Bombax ceiba, Vetiveria* sp*, Themeda* sp*, Saccharum* sp, etc. Hog deer prefers *S. spontaneum* and *S. spontaneum-P karka* assemblages (Peet *et al.,* 1999) and Rhinoceros frequently feeds *S. spontaneum* (Jnawali & Wegge, 1993). *Phragmites* is also important for mallard and warbler birds. Aquatic macrophytes are important both as biotic and abiotic factor (Wychera *et al.,* 1990) contributing shelter and food to fish, waterfowls and macro-invertebrates including larval aquatic insects.

Trees *Acacia catechu* (Khayar), *Dalbergia sissoo* (Sissoo), *Bombax ceiba* (Simal), *Syzygium cumini* (Haldu), *Malotus philippensis* (Rohini), *Adina cordifolia* (Faldu), etc. and grasses *Vetiveria* sp.*, Themeda* sp*, Saccharum* sp., etc. were common in flood plains. On flood plains, the presence of tree seedlings associated with *Saccharum spontaneum* indicates that the sites are not climax and since the sites dry up during summer. Moreover marshy grasses *Arundo, Phragmites, Juncus* species were abundant in flood plains and river banks. The flood plains of Mahakali River characterized with *Acacia-Dalbergia* and *Bombax-Ficus glomerata-Eugenia jambolina-Trewia nudiflora-Mallotus phillipensis*.

Species diversity increased when moving from water to the terrestrial habitats and it was prominent as moving from water edge to marshy lands, whereas the species richness increased with increasing wetness (fig. 3). Flood plain vegetation gradually changes from a more typical wetland to the terrestrial community due to decrease in soil wetness along the gradient between flooded and dry areas (Turner, 1991). Increase in species richness with decrease in water depth is because of adaptation of the species to changing environment (Grime, 1979). The result is

consistent to the findings of Sah (2002), the floodplain islands were highly grazed *Dalbergia sissoo-Acacia catechu* forests with devoid of understory woody vegetation whereas the lightly grazed *D. sissoo*-mixed forests with a well-developed second canopy layer, comprising woody species were seen in transition of floodplains and forests. Most of the Mahakali riverbank areas are closely associated with diverse types of micro-habitats, flourishing plant species diversity. They are bordered with mixed Sal forest and its associative riverine forest species and steep cliffs and rocks.

Socio-economy and wildlife

Of total 501 species reported from Darchula district (Kunwar *et al.*, 2016), 140 species were recorded only from Mahakali river corridor in the present survey. A total of 78 species (55 percent) were ethnobotanically important as folklore medicine, vegetable, edible, fodder and timber. Similar number of 78 medicinally important plant species were reported from adjoining villages of Mahakali River (Pant & Panta, 2004). A total of 64 ethnomedicinal plants were catalogued in previous study (Burlakoti & Kunwar, 2009) from the same area. Thus we can infer that the area is rich for ethnomedicinal plant species. *Ficus hispida* (Khasru), *Acorus calamus* (Bojho), *Aegle marmelos* (Bel), *Jatropha curcas* (Sajiwan, Inna), *Bombax ceiba* (Simal)*, Cyperus* species (Mothe), *Eclipta prostrata* (Bhringraj), etc. were ethnobtanically used, of them *Eclipta prostrata* (Bhringraj) and *Acorus calamus* (Bojho) were semi aquatic macrophyte folkloric to the study area. However they were locally threatened once the exploitation outpaced the conservation. The Mahakali river bank is worth harbouring nationally threatened and prioritised for conservation species such as *Acacia catechu, Aegle marmelos, Alstonia scholaris, Asparagus racemosus, Bombax ceiba, Calamus tenuis*, *Curciligo orchoides, Oroxylum indicum, Shorea robusta,* etc. Owing diverse and inaccessible niches like steep cliffs and rocks, deep gorge riverine forests, and mixed deciduous forests are interspersed with river flanks, Mahakali provided unique habitats for habitat specific plants and animals. Moreover, a remarkable number of smaller mammals, birds as well as reptilian species take refuge in such habitats. The flood plains and riverbanks of Mahakali at Dharmagad, Pancheswor and Binayak of Baitadi district are important for otters, periphytons (snails, nymphs and damselfly), lizards, algae, etc. as water holes, earthen holes, drift logs, peebles, etc. Snakes, frogs and small aquatic snails were seen at Gokuleswor. Katle fish were seen more in low velocity waters whereas Asla fish were prone to decrease because of lentic flow at low-lands (Wychera *et al.,* 1990). Observations of pugmarks and footprints of higher mammals at Mahakali river-banks uncovered the importance of river beds to the animals. Ungulate populations are best in combination of grassland, riverine forest and water body system (Jnawali & Wegge, 1993).

Mahakali wetland supports limited flood plains and is supported by a number of tributaries and is associated with large flanks of riverine forests. Plant succession was conspicuous and mosaic as one goes farther from water edge to forest edge, the *Phragmites karka* was gradually replaced by *Sphenoplectus, Ipomoea*, and *Saccharum* species. At farther end, riverine species *Vetiver, Themeda, Acacia catechu, Dalbergia sissoo, Bombax ceiba,* and riverine species *Eugenia jambolina*, *Aegle marmelos, Lannea coromandelica, Mallotus phillippensis,* etc. succeeded consecutively. The succession was fueled by soil moisture, temperature and physiographical gradients. As the richness and plant growth-forms increased from hydric to mesic niches, both

the species diversity and richness were increased. Only 27 percent plant species (140 species) of the district were recorded in the present communication, they were important under rubrics ethnobotanicla and ethnomedicinal. So, this study serves as a baseline and reference for phyto-ecological assessment of Mahakali river system at temporal scale.

ACKNOWLEDGEMENTS

Authors would like to acknowledge local people and communities who helped during field visits by providing their invaluable insights and knowledge of Mahakali wetland, vegetation, wildlife and their management. Authors are also thankful to Water Resource Consult, Kathmandu for providing supports for fieldwork and anonymous reviewers for comments.

REFERENCES

BHANDARI, B B (1993) The current status of wetlands in Nepal. *In* Isozaki, H; Ando, M; Natori, Y (eds) *Towards wise use of Asian wetlands.* International Lake Environment Conservation Foundation, Japan; pp 103–111.

BHANDARI, B B (1996) An inventory of Nepal's terai wetlands. IUCN Nepal; 309 pp.

BHANDARI, B B (2009) Wise use of wetlands in Nepal. *Banko Janakari* Special issue**:** 10–17.

BPP (1995) Biodiversity profile of terai/siwalik physiographic zone. Department of National Parks and Wildlife Conservation, Kathmandu, Nepal.

BURLAKOTI, C; KUNWAR, R M (2008) Folk herbal medicines of Mahakali watershed area, Nepal. *In* Jha, P K; Karmacharya, S B; Chhettri, M K; Thapa, C B; Shrestha, B B (eds) *Medicinal plants in Nepal: an anthology of contemporary research.* Ecological Society of Nepal; pp 188–194.

CBS (1998) A compendium on environmental statistics 1998 Nepal. Center Bureau of Statistics, Kathmandu, Nepal.

CBS (2013) State of the environment Nepal. Kathmandu, http://www.rrcap.unep.org/reports/soe/nepal_water.pdf.

C-CON AND COWEL INTERNATIONAL (1994) EIA of the Pancheswaor multipurpose project on Nepal Himalaya. Government of Nepal, Kathmandu.

CIWEC (1997) Upper Karnali Hydroelectric Project Environmental Impact Assessment, Vol I. EIA executive summary and main report. CIWEC Kathmandu, Nepal.

COOK, C D K (1996) *Aquatic and wetland plants of India.* Oxford University Press, New Delhi, India; 385 pp.

CORTES, R M V; VARANDAS S; HUGHES, S J; FERREIRA, M T (2008) Combining habitat and biological characterization: ecological validation of the river habitat survey. *Limnetica* 27(1): 39–56.

COWARDIN, L M; CARETR V; GOLET, F C; LARVAE, E F (1979) Classification of wetlands and deep-water habitats of the US. FWS/OBS 79/31 US Fish & Wild Life Services, Washington DC, USA.

CSUWN (2009) Conservation and sustainable use of wetlands in Nepal. CSUWN, Kathmandu, Nepal. *Banko Janakari* Special issue: 40-42.

DABADGHAO, P M; SHANKARNARAYAN K A (1973) *The grass cover of India.* Indian Council of Agricultural Research, New Delhi, India; 713 pp.

DDP (2004) District Development Profile of Nepal. Information Sector Research and Study Centre, Kathmandu, Nepal.

DHM (1999) Water quality of rivers of Nepal (unpublished). Department of Hydrology and Meteorology, Kathmandu, Nepal.

DINERSTEIN, E (1979) An ecological survey of the Royal Karnali-Bardia Wildlife Reserve, Nepal. Part I.Vegetation, modifying factors, and successional relationships'. *Biological Conservation* 15: 127–150.

GRIME, J P (1979) *Plant strategies and vegetation processes*. Wiley, New York.

GROLUND, E (2012) The recovery of two polluted subarctic lakes—towards nutrient management or a pristine state? *Water* 4(4): 793–814.

HMGN (1991) Pancheswor multipurpose project: field investigation within Nepal territory. Final report, I-IX. Kathmandu, Nepal.

HMGN (1994) EIA of the Pancheswor multipurpose project of Nepal tetritory. C-CON and COWEL International Kathmandu, Nepal.

HMGN (2000) Preliminary EIA study: stage I. The Bheri-Babai hydroelectric project. Vol I. Baseline report,Kathmandu, Nepal.

HPC (1989) The upper Karnali hydroelectric project: prefeasibilty study of the Karnali bend site. KRIA, final report. Himal Power Consultants, Nepal.

HRIVNAK, R; OTAHELVO, H; VALACHOVIK, M (2007) The relationship between macrophyte vegetation and habitat factors along a middle-size European river. *Polish Journal of Ecology* 55(4): 717–729. http://www.mope.gov.np/environment/2000/state2000.pdf

JAMES, E J (1995) Managing the wetlands and their watersheds. *Yojana* 39(182): 43–50.

JICA AND NEW ERA (2000) Preliminary environmental impact assessment study on Bheri Babai hydroelectricity project. Baseline report. Government of Nepal, Kathmandu, Nepal.

JNAWALI, S R; WEGGE, P (1993) Space and habitat use by a small re-introduced population of greater One horned rhinoceros (*Rhinoceros unicornis*) in Royal Bardia National Park in Nepal –a preliminary report *In* RYDER, A O (ed) *Rhinoceros biology and conservation*. *Proceedings of an international conference of Zoological Society of San Diego,* San Diego, USA; pp 208–217.

KAUL, S (2003) Wetland conservation and management; a national perspective. Vol 4. Chilika Development Authority and Wetland International. South Asia. Orissa, India.

KHAN, M S; HALIM, M (1987) *Aquatic angiosperms of Bangladesh.* Bangladesh Agricultural Research Council, Dhaka, Bangladesh; 120 pp.

KOHLER, A (1978) Methods of mapping of freshwater flora and vegetation biotypes. *Landschaft und stadt* 10(2): 73–85.

KUNWAR, R M; SHRESTHA, K; DHUNGANA, S K; SHRESTHA, P R; SHRESTHA, K K (2010) Floral biodiversity of Nepal: an update. *Journal of Natural History Museum* 25: 295–311.

LAURIE, W A (1978) *The Ecology and Behaviour of the Greater One-homed Rhinoceros*. Ph.D Dissertation. Cambridge: University of Cambridge.

LEHMKUHL, J F (1989) *The ecology of a south-Asian tall grass community*. PhD dissertation, University of Washington, Seattle, USA.

MOOL, P K; BAJRACHARYA, K; SAMJAL, R; JOSHI, S P (2001) Inventory of glaciers, glacial lakes and glacial lake outburst flood: monitoring and early warning systems in the Hindu-Kush Himalaya. ICIMOD, Kathmandu, Nepal.

PANT, S R; PANTA, I R (2004) Indigenous knowledge on medicinal plants in Bhagawati VDC, Darchula, Nepal. *Botanica Orientalis* 4: 79–81.

PEET, N B; WATKINSON A, J; BELL D, J; KATTEL, B (1999) Plant diversity in the threatened subtropical grasslands of Nepal. *Biological Conservation* 88: 193–206.

PODDAR, P; PUSTE, A M; SENGUPTA, K (2001) Wetlands and their agronomic utilization. Environment, Agriculture and Pollution in South Asia. *In* JHA, P K; BARAL, S R; KARMACHARYA, S B; LEKHAK, H D; LACOUL, P; BANIYA ,C B (eds) *Proceeding of the International Conference on Environment and Agriculture*, Ecological Society of Nepal; pp 410–413.

POUDEL, B S (2009) Wetland conservation in Nepal: policies, practices, problems and possibilities. *Banko Janakari* Special issue**:** 5–9.

PRESS, J R; Shrestha K K; SUTTON, D A (2000) Annotated checklist of the flowering plants of Nepal. Natural History Museum, London, UK.

RAJBANSI, K G; GURUNG, T B (1994) Wetlands and fisheries: prospects and constraints. *In* BHANDARI, B; SHRESTHA, T B; MCEACHERN, J (eds) *Safeguarding wetlands of Nepal*. *Proc of workshop on wetlands management in Nepal*, Kathmandu; pp 66–76.

ROACH, J (2015) Faceless Indus Valley city puzzles archaeologists. http://science.nationalgeographic.com/science/archaeology/mohenjo-daro/ accessed on July 8.

SAH, J P (1993) Wetland vegetation and its management: a case study in Koshi Tappu wildlife region, Nepal. M.Sc. thesis AIT, Bangkok, Thailand.

SAH, J P (1997) Koshi Tappu Wildlife Reserve: Ramsar site. IUCN Nepal; 254 pp.

SAH, J P (2002) Vegetation dynamics and their implications for the management of wetlands in the lowlands of Nepal. ProQuest ETD Collection AAI3059789, FIU, US.

SENFT, A (2009) Species diversity patterns at ecotones. Master's thesis, University of North Carolina, USA.

SHANNON, C E; WEINER, W (1963) The mathematical theory of communication. Urbana, University of Illinois press, USA; 117 pp.

SHRESTHA, B N (2012) Rivers of Nepal. https://bordernepal.wordpress.com/tag/koshi/

SHRESTHA, P (2000) Vegetation analysis of aquatic macrophytes by using line intercept in lake Phewa, Nepal. *Ecoprint* 7: 7–14.

SMEC (1999) West Seti hydro electric project—environment impact assessment: ecological studies, Vol 5. SMEC International Ltd, Kathmandu.

SUKUMAR, R (1989) *The Asian elephant: ecology and management*. Cambridge University press, Cambridge, UK.

TRIVEDI, R K; GOEL, P K (1986) Chemical and biological methods for water pollution studies. Environmental publications, Karad, India; 248 pp.

TURNER, K (1991) Economics and wetland management. *Ambio* 20: 59–63.

USHARANI, K; UMARANI, K; AYYASAMY, P M; SHANI, K; LAKSHMNA, P P (2010) Physico-chemical and bacteriological characteristics of Noyyal River and ground water quality of Perur, India. *Journal of Applied Scienc and Environmental Management* 14(2): 29–35.

WYCHERA, U; DIRRY, P; JANAUER, J A; BARRETT, P A; GREAVES, M P; MURPHY, K; POITERSE, E; WADE, P M; WANSTEN, M (1990) Macrophytes of the "New Danube" (Vienna): biological and management aspects. *Proceedings of the 8th International Symposium on Aquatic Weeds,*3–17 August 1990. Uppsala, Sweden; pp 249-255.

ZOBEL, D B; JHA, P K; YADAV, U K R; BEHAN, M J (1987) *A practical manual for ecology.* Ratna Book Distributors,Kathmandu, Nepal; 149 pp.

TABLE 3. Characteristics and species composition of each study site.

Site	Wetland type and habitat	Phytoplanktons	Macrophytes at water edge to 50 m	Macrophytes at 50 m to 100 m	Macrophytes at 100 m to 200 m
Lali khola, Lali, Darchula (1960 ft), Water pH 7.7	River, floodplain, stream (Confluence of Lali/Gaj khola, small flood plain is associated with moderately disturbed Sal forest)	*Anabaena* sp. *Oscillatoria* sp. *Coscinodiscus* sp. *Cladophora* sp. *Navicula* sp.	*Polygonum barbatum, Bidens biternata, Euphorbia hirta, Cynodon dactylon, Hemarthria compressa*	*Justicia adhatoda, Woodfordia fruticosa, Dalbergia sissoo, Triumphetta bartramia, Syzygium cumini*	*Shorea robusta, Adina cordifolia, Syzygium cumini, Bombax ceiba*
Chameliya, Gokule, Darchula (2151 ft), Water pH 7.6	River, floodplain, seasonal stream, secondary channel associated with agricultural lands and settlement in both sides	*Cladophora* sp. *Navicula* sp. *Oedogonium* sp. *Melosira* sp. *Chara* sp. *Euastrum* sp. *Coscinodiscus* sp.	*Equisetum* sp. *E. hirta, Justicia adhatoda, Phyllanthus amarus, Eragrostis tenella*	*Desmodium triflorum, Ficus hispida, Polygonum barbatum, Solanum xanthocarpum, Phyllanthus emblica*	*Mallotus philippense, Zyziphus incurva, Sapium insigne*
Mahakali, Binayak, Baitadi (1740 Ft), Water Ph 7.4	River, floodplain, backwater, seasonal stream (confluence of Melasue, small flood plain associated with agricultural lands and settlement in Nepal territory, Sal forest in India)	*Clostridium* sp. *Oedogonium* sp. *Syndera* sp.	*Ageratum conyzoides, Euphorbia hirta, P. barbatum, Saccharum spontaneum, Eupatorium odoratum*	*A. conyzoides, Truimphetta bartramia, Lindernia ciliata, Eclipta prostrata, Xanthium strumarium*	*Syzigium cumini, Adina cordifolia, Phyllanthus emblica, Ficus palmata*

Mahakali, Pancheswor, Baitadi (1669 ft), Water pH 7.5	River features with rocks and stones and dense forests of *Sal, Simal, Khayar, Rohini, Sissoo, Karma*, etc.	*Anabaena* sp. *Cladophora* sp. *Clostridium* sp. *Microcystis* sp. *Navicula* sp. *Oscillatoria* sp.	*Equisetum* sp. *Phyllanthus amarus,* *Hygrophila polysperma,* *P. emblica,* *C. dactylon*	*M. philippensis,* *Dalbergia sissoo,* *S. spontaneum,* *Phragmites karka,* *Aegle marmelos*	*Dalbergia sissoo,* *Syzygium cumini,* *Pyrus pashia, F hispida, Jatropha curcas, Calicarpa arborea*
Mahakali, Dharmagad, Baitadi (1660 ft), Water pH 7.5	River, floodplain, secondary channel, seasonal stream associated with large rocks and steppe cliffs and dense forests of Sissoo, Simal, Khayar, Rohini, Bel, Karma, etc.	*Anbaena* sp. *Oscilaltoria* sp. *Euastrum* sp. *Microsystis* sp. *Clostridium* sp. *Syndera* sp.	*A. conyzoides,* *S. spontaneum* *Eleusine* sp. *Parthenium hysterophorus,* *C. dactylon*	*S. spontaneum,* *P. karka* *Salix* sp. *Ficus racemosa* *Alternanthera sessilis*	*Acacia katechu,* *A. marmelos, D. sissoo, Lannea coromandelica, P. emblica*
Rupaligad, Samnaya, Dadeldhura (1297 ft), Water pH 7	River, floodplain, stream (Confluence of Rupaligad and Mahakali, narrow flood plains, is used for irrigation purpose.	*Cladophora* sp. *Navicula* sp. *Oedogonium* sp. *Melosira* sp.	*Polygonum* sp. *Persicaria capitata* *Ficus semicordata* *Ageratum conyzoides* *Calotropis procera* *Dalbergia sissoo* *Amaranthus* sp.	*Biden biternata,* *Eupatorium adenophorum* *Adina cordifolia* *Solanum nigrum* *Boehmeria* sp. *Xanthium* sp. *Gynura* sp. *Artemisia* sp.	*Dalbergia sissoo, Lannea coromandelica,* *Adina cordifolia,* *Bombax ceiba,* *Acacia catechu*

Sirsegad, Sirse, Dadeldhura (1197 ft), Water pH 7.2	River, floodplain, stream, secondary channel associated with agricultural lands and settlement in both sides.	*Anbaena* sp. *Oscilaltoria* sp. *Euastrum* sp. *Microsystis* sp.	*Polygonum* sp. *Kyllinga* sp. *Desmodium triflorum, Cyperus* sp., *Psidium guajava, D. sissoo, A. conyzoides, Zyzyphus mauritiana, Albizzia* sp., *Marsilea* sp.	*Artemisia sp, Acorus calamus, Amaranthus spinosus, Lantana camara, Justicia adhatoda, Xanthium* sp., *Solanum nigrum,*	*Shorea robusta, Aegle marmelos, Bombax ceiba, Lagerstroemia parviflora, Bauhinia purpurea, Schleichera oleosa, Terminalia bellirica, Semecarpus anacardium*
Mahakali, Parigaun, Dadeldhura (1019 ft), Water pH 6.5	River, streams, secondary channels of Rangun khola, extensive flood plains.	*Oedogonium* sp. *Melosira* sp. *Chara* sp. *Euastrum* sp.	*Z. mauritiana, L. camara, Cactus sp, Cassia tora, Typha angustifolia, Ipomoea carnea, Ephera gerardinia, Cynodon dactylon, Cyperus rotundus, I.cylindrica,*	*Imperata culindrica, Vetiver sp, Athyrium* sp., *Eupatorium adenophorum, A. conyzoides,*	*Mallotus philippensis, B. ceiba, D. sissoo, Justicia adhatoda, A. catechu, L. coromandelica, Murraya koenigii, Sapium insigne, A. cordifolia*
Mahakali, Chandani, Dadeldhura (1021 ft), Water pH 6.8	River, floodplain, seasonal stream features with sand, rocks, stones and boulders, close to settlement area.	*Euastrum* sp. *Microsystis* sp. *Clostridium* sp.	*Cassia tora, P. guajava, Calotropis procera, Cyperus* sp., *Imperata* sp., *A. conyzoides*	*Lantana camara, Salix* sp., *Solanum xanthocarpum, Ipomoea carnea, D. sissoo, Nyctanthus* sp.	*B. biternata, Woodfordia fruticosa, Lannea coromandelica, Ficus semicordata, Euphorbia hirta, Urena lobata*

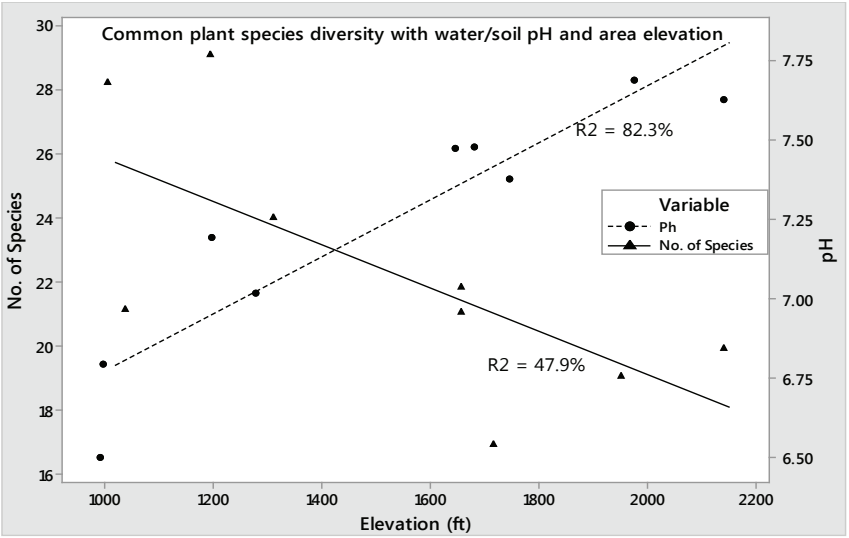

FIG. 2. Species diversity with pH and elevation.

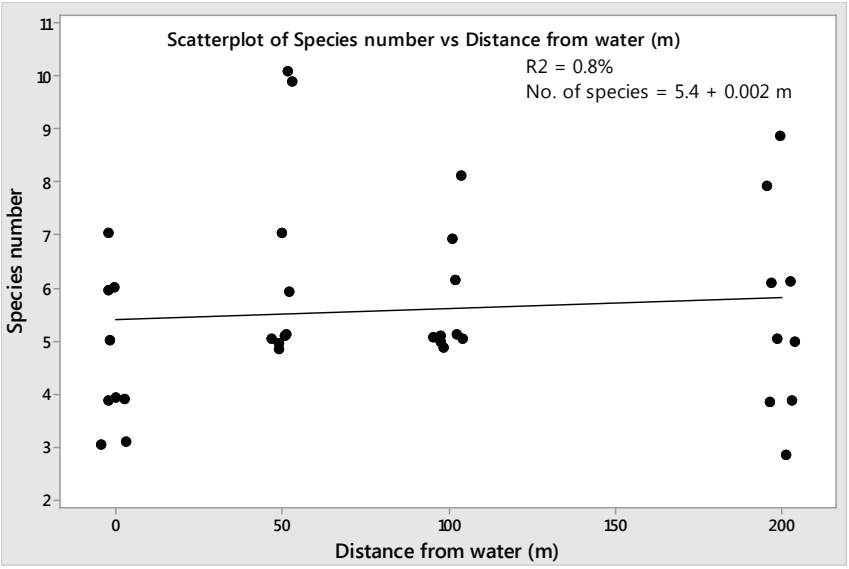

FIG. 3. Species diversity of phytoplanktons and macrophytes.