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Original Article

Valley bottom wetland plant communities and their relationship with soil factors in the Gangtey-Phobji Wetland, Wangdi Phodrang, Himalayan, Bhutan

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Abstract

Valley-bottom wetlands are valuable assets as they deliver many ecosystem services to humankind. This study determines the plant communities and distribution in the Gangtey-Phobji Valley bottom wetland of Wangdue Phodrang, Bhutan. Used 100 m line transect with random sampling (1x1 m^2, 4x4 m^2, 10x10 m^2) quadrats were used for herbs, shrubs, and trees respectively to record floristic composition. In addition, the hierarchical cluster analysis (HCA) and indicator species analysis were performed to define plant communities and canonical correspondence analysis (CCA) to investigate relationships between environmental variables and plant communities. The present study recorded 241 plant species from 173 genera and 75 families in the wetland. Cluster and indicator species analysis identified four community types, and three species were named from the highest indicator value (IV) in each community. Essential variables that affect the plant communities were the edaphic factors such as available nitrogen, soil organic matter, calcium, magnesium, and sodium ions.

Keywords: plant community, valley bottom wetland, floristic composition, Himalayan, Bhutan

1. Introduction

The wetlands are naturally diverse ecosystems that provide crucial habitat to a wide range of floral and faunal elements and ecologically susceptible systems in the world (Hebb, Mortsch, Deadman, & Cabrera, 2013; Skeffington *et al*., 2006; Wetser, Liu, Buisman, & Strik, 2015). The widely used definition of the wetland is the **"**areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters (Ramsar Convention Secretariat, 2013). Wetlands include a wide range of wet environments that differ in a landscape, soil, water regime climate, vegetation, and anthropogenic activities (Ruto, Kinyamario, Etich, Akunda, & Mworia, 2012). Wetlands play an essential role in providing ecosystem services such as climate regulation, carbon sequestration, flood abatement, freshwater supply, and biodiversity conservation (Momblanch, Connor, Crossman, Paredes-Arquiola, & Andreu, 2016; Revenga, Brunner, Henninger, Kassem, & Payne, 2000).

Valley bottom wetlands are the critical repository of richer floral and faunal diversity than other habitat types (Munishi *et al*., 2011). However, significant changes due to agricultural intensification, tourist development, cattle grazing, and anthropogenic intervention have threatened the wetland ecosystem (Gherardi, Catarina, & Stefano, 2009; Gordon & Duncan, 1988). Similarly, habitat alterations by cultivation and cattle grazing cause changes in plant communities and the extinction of native species (Meng *et al*., 2017). Although several factors typically influence wetland plant communities, soil properties, elevation, and disturbances are recognised as the most common and influential factors that

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cause the degradation of wetland ecosystems (Welch, Davis, & Gates, 2006).

Results were different based on sites and habitats, making ecologists intrigued with mixed results (Yang *et al*., 2015). Therefore, understanding wetland plant communities and their relationship with environmental variables and soil nutrients is a fundamental component for sustainable and appropriate conservation strategies in wetlands (Zheng *et al*., 2019).

Wetlands in Bhutan generally include fens, rice fields, bogs, marshes, vernal pools, swamps, springs, and places near water-logged areas, glacial lakes, dams, and rivers (Sherub, Wangdi, & Norbu, 2011; Tendar, Coper, & Sridith, 2020; Watershed Management Division, 2017). The top-down approaches of wetland classification based on hydrogeomorphic variables (Sieben *et al*., 2016) best represent Gangtey-Phobji Valley as valley bottom wetland.

The wetland's landscape of panoramic scene is further captivating and revered by the 16th-century Gangtey Monastery, becoming a popular destination for domestic and international tourists in Bhutan (Chaudhary *et al*., 2017). The vicinity of the valley bottom wetland is surrounded by Gangtey and Phobji blocks (gewogs in Dzongkha). Agriculture and livestock are the primary sources of livelihood that pose immense threats to wetlands. The large area of cultivating potatoes and continuous grazing by yaks, cows and horses may significantly impact the wetland's land cover, plant community and composition (Phuntsho, 2010).

The scientific exploration on the Gantey-Phobji Valley bottom wetland is limited only to the soil formation in Phobjikha Valley (Caspari, Bäumler, Norbu, Tshering, & Baillie, 2008), habitat preferences and conservation threats to vulnerable crane species Black-necked crane (Namgay & Wangchuk, 2016), effects of natural and human disturbances on wetland ecosystem (International Centre for Integrated Mountain Development, ICIMOD, & Royal Society for Protection of Nature, RSPN, 2014), the impact of human settlements on the plant diversity in the wetlands (Lhamo, Kabir, & Uddin, 2020) and on the impact of land cover change on a mountain ecosystem and its services (Chaudhary *et al*., 2017). But scientific studies on the plant communities and their relationship with environmental variables have remained unexplored in the bottom of the Gangtey-Phobji Valley wetland. Therefore, our study's objectives were to (1) investigate plant communities and (2) determine the relationship between plant communities and environmental variables in the Gangtey-Phobji Valley bottom wetland of Wangdue Phodrang in Bhutan. This study was necessary to address the relationship between plant communities due to change in environmental variables over decades. Further, findings from the study may help policymakers, relevant organisations and stakeholders for the sustainable conservation of biodiversity and management of the wetland.

2. Materials and Methods

2.1 Study area

The Gangtey-Phobji Valley bottom wetland is a wide glacial valley with meandering streams running through the open valley. It is approximate with an area of 97,000 hectares and elevation of about 3,000 m above sea level, which lies at 27°26'46"N and 90°11'08" E (Figure 1). Therefore, the area is considered one of the most extensive high-altitude wetlands, and it is one of the Ramsar wetland sites in the country (International Centre for Integrated Mountain Development, ICIMOD, & Royal Society for Protection of Nature, RSPN, 2014). Furthermore, the mentioned valley bottom wetland is famous habitat for an endangered Black-necked Crane (*Grus nigricollis*). They migrate from the Tibetan Plateau in winter. Therefore, the areas are conserved as the Gangtey-Phobji Wetland area and listed under Ramsar sites (ICIMOD & RSPN, 2014).

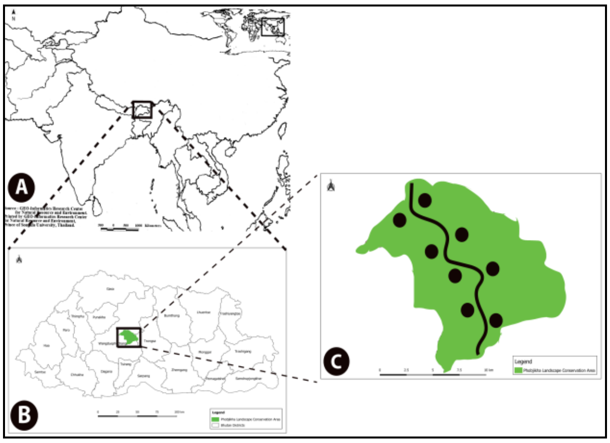

Figure 1. A: Map showing Bhutan in Asia, B: Bhutan map showing Wangdi Phodrang District, C: Map showing study sites with line transect points

2.2 Field survey

Vegetation data were collected in March-November 2020 as most plants' peak months to bloom fully. A 100 m line transect with random sampling were used to collect plant cover and species. Within the 100 m line transect, used 1x1 m^2, 4x4 m^2, and 10x10 m^2 quadrats for herbs, shrubs, and trees, respectively, for the whole data collection (Kent, 2012). Using Braun-Blanquet cover scale (Kent, 2012): +(<1%), 1(1-5%), 2(6-25%), 3(26-50%), 4(51-75%), 5(76-100%), percent cover visually estimated in each quadrat were converted. The nomenclature for the vascular plants were based on Flora of Bhutan (Grierson & Long, 1983, 1984, 1987, 1991, 1999, 2001). Voucher specimens and photographed plants with clear images were taken to the National Biodiversity Centre (NBC), Herbarium, Serbithang, Thimphu for confirmation. Unknown plants were identified with detailed taxonomic literature. Faecal pats were recorded in each quadrat and visually estimated the grazing intensity (Collins, 2004). The elevation and coordinates were recorded using GPS Garmin eTrex 35.

The soil samples from 0-30 cm depth were collected using a soil auger from each quadrat and put in clean polythene bags with proper labelling. Samples were air-dried and sieved thoroughly, making fine textures. The sieved soil samples were taken to the National Soil and Plant Analytical Laboratory, Department of Agriculture, Semotokha, Thimphu, Bhutan, to analyse soil chemical properties.

2.3 Data analysis

Hierarchical cluster analysis had been applied with the flexible beta linkage method (β = -0.25) and Sorensen (Bray-Curtis) similarity with species cover of each quadrat as primary input data. First, determine the appropriate number of groups in the cluster analysis by performing the indicator species analysis and then plant communities' characteristics were obtained.

Using the Monte Carlo test with 4999 permutations, the significance of indicator values was determined (Dufrene & Legendre, 1997). Each plant community were classified from the three species with the highest significant values ($p < 0.002$) after multiple levels of clustering (McCune & Grace, 2002). Canonical correspondence analysis (CCA) were performed to find a relationship between environmental variables and plant species in the study area (Sasaki *et al*., 2013; Sieben *et al*., 2016).

The species-environment relationships were analysed, selecting species with higher indicator values to identify primary relationships between environmental variables and plant species (Fan *et al*., 2017). Environmental variables that are not correlated with any axes were removed using the default cutoff value of 0.20 during the first analysis. Then, the cluster analysis, canonical correspondence analysis (CCA), and indicator species analysis was conducted with the help of program PC-ORD version 7.07 (McCune & Mefford, 2018). Soil samples were analysed using the Bray and Kurtz analyser for available phosphorous, nitrogen using the Kjeldehl analyser. For carbon Walkley and Black method had been applied. For sodium, magnesium, and calcium ions in 1-mole neutral ammonium acetate, flame photometer and soil pH in a ratio of 1:2:5 soil water suspension at the Soil and Plant Analytical Centre, Semotokha, Thimphu, Bhutan were undertaken (Research, Extension, and Irrigation Division, 1993).

3. Results

3.1 Plant communities and habitats

The presence-absence matrix of 241 plant species and 170 plots were used to analyse plant communities by hierarchical cluster and indicator species analysis (Figure 2). Based on the multiple indicator species analysis, plants in the study area were grouped into four community types (Table 1). In addition, three dominant species that characterised the community were selected based on the indicator value (IV) classified by Hierarchical cluster and indicator species analysis.

Community I: Found mainly in bog habitats, mostly in the bottomlands and gentle slope, and even a meandering stream. Species such as *Aster neo-elegans* Grierson., *Bistorta affinis* Greene., *Carex notha* Kunth., *Gaultheria nummulariodes* D. Don., *Halenia elliptica* D. Don., *Rhododendron thomsonii* Hook. f. and *Yushania microphylla* (Munro) R.B. Majumdar characterises this habitat.

Community II: Occurred in open sites, drained, mainly at the edge of roads, and total cattle grazing sites. It is dominated by *Anaphalis triplinervis* (Sims) C.B. Clarke., *Cirsium falconeri* Petr., *Cyanotis vaga* (Lour.) Schult. & Schult.f., *Rosa sericea* Lindl., *Jacobaea analoga* (DC) Veldkamp and *Trifolium repens* L. There is no discharge of water from the underground and no standing water during the growing season.

Community III: It is associated with flood basins, depressions, and usually seasonally inundated habitats. The community were characterised by elements *Carex alopecuroides* D. Don., *Eleocharis atropurpurea* (Retz.) J. Presl & C. Presl., *Hypericum japonicum* Thunb., *Juncus thomsonii* Buchenau., *Schoenoplectus juncoides* (Roxb.) Palla and *Xyris indica* Willd ex Kunth.

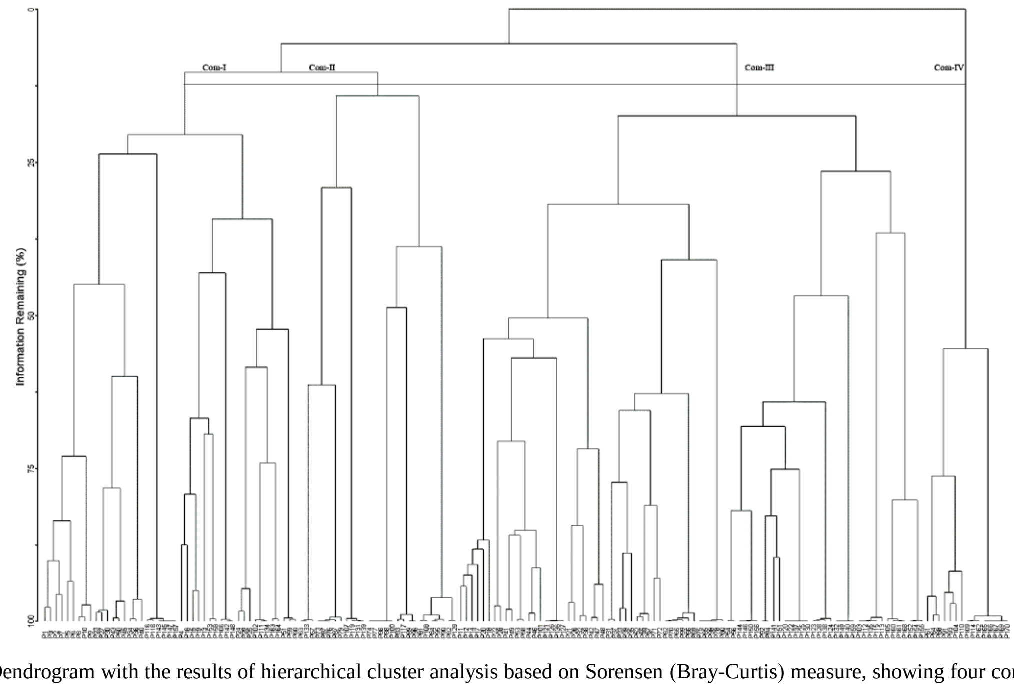

Figure 2. Dendrogram with the results of hierarchical cluster analysis based on Sorensen (Bray-Curtis) measure, showing four community types (I-IV) with 12.5% remaining information in the Gangtey-Phobji Valley bottom wetlands, Wangdue Phodrang, Bhutan.

Community IV: It occurred mainly adjacent to the seasonal tributaries flows from uplands of human settlement areas and where soil remains hydric for a certain period.

It is characterised by *Chusua pauciflora* (Lindl.) P.F. Hunt., *Pedicularis siphonantha* D. Don., *Poa polycolea* Stapf., *Poterium filiforme* Hook. f and *Ranunculus tricuspis* Maxim. Communities II and IV record more cattle faecal pats and weed species such as *Cyanotis vaga* (Lour.) Schult. & Schult.f., *Persicaria hydropiper* (L.) Delabre. This community associated with *Rumex acetosella* Holl ex Meisn., *Rumex nepalensis* Spreng and *Trifolium repens* L.

3.2 Environmental variables and plant species relationships

Canonical correspondence analysis was performed to investigate the relationship between the nine soil variables and wetland vegetation. The first CCA axis indicated significant (p=0.001) from permutation tests with 998 runs (Figure 3). Simple randomisation tests for axes two and three are not reflected as these may bias the p values. The eigenvalues of the first and second axes for the species-environment were 0.150 and 0.097. These had represented 3.1% and 2.0% of the 5.1% total variation in the data of species-environment.

The distribution of *Ligularia fischeris* (Ledeb.) Turcz., *Poterium filiforme* Hook. f and *Ranunculus tricuspis* Maxim were mainly influenced by available nitrogen. The distribution of *Drosera peltata* Thunb., *Hypericum japonicum* Thunb., *Impatiens radiata* Hook. f., *Juncus thomsonii* Buchenau., *Rhododendron thomsonii* Hook. f and *Urticularia aurea* Lour were mainly influenced by sodium ions, soil organic matter, calcium ions and magnesium ions. Maximum species of community two were situated on axes three of biplot and recorded mostly the area with acidic with no significant differences.

Table 1. Four plant communities with indicator values (IV) of first three plant species in Gangtey-Phobji Valley bottom wetlands, Wangdue Phodrang, Bhutan

Community type	Family	Indicator species	Code	IV	*P* value
Community I	Gentianacee	*Halenia elliptica* D. Don	Halelp	40.00	0.0002
	Ericaceae	*Rhododendron thomsonii* Hook. F	Rhotho	32.10	0.0008
	Poaceae	*Yushania microphylla* (Munro) R.B. Majumdar	Yusmic	30.70	0.0020
Community II	Fabaceae	*Trifolium repens* L	Trirep	59.30	0.0002
	Asteraceae	*Jacobaea analoga* (D C.) Veldkamp	JacAna	42.60	0.0002
	Asteraceae	*Anaphalis triplinervis* (Sims) C.B. Clarke	Anatrl	38.40	0.0002
Community III	Xyridaceae	*Xyris indica* Willd. ex Kunth	Xyrind	90.00	0.0002
	Cyperaceae	*Eleocharis atropurpurea* (Retz.) J.Presl & C.Presl	Eleatr	85.50	0.0002
	Cyperaceae	*Carex alopecuroides* D. Don	Caralo	81.20	0.0002
Community IV	Orobanchaceae	*Pedicularis siphonantha* D. Don	Pedsip	49.90	0.0002
	Poaceae	*Poa polycolea* Stapf	Poapol	30.50	0.0002
	Rosaceae	*Poterium filiforme* (Hook. F.) Hand. -Mazz	Potfil	25.00	0.0010

Showing community types named three plant species with highest indicator values (IV) from the indicator species analysis with significant indicator values (p<0.002)

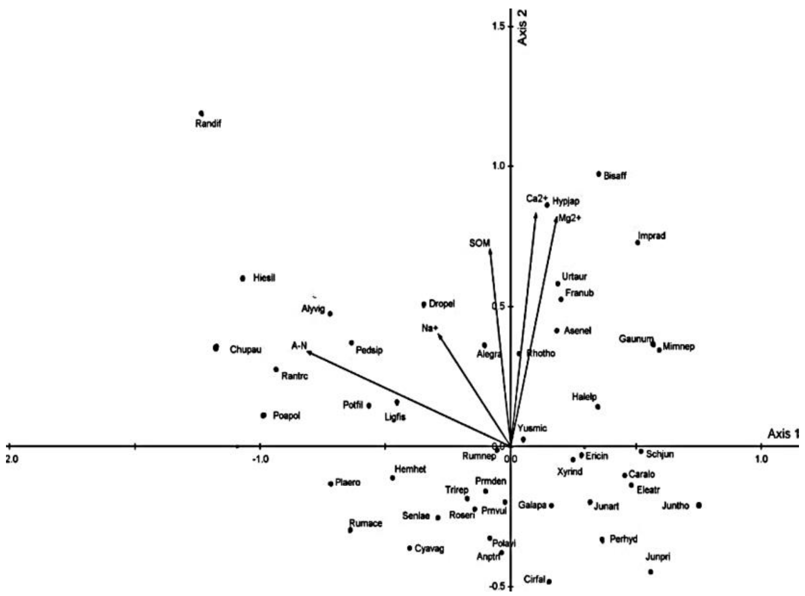

Figure 3. Canonical correspondence analysis (CCA) ordination diagram for plant species and soil variables. The plant species are represented by (•) and codes, environmental variables with arrows, the length of a vector is proportional to its importance. The angle between two vectors reflects the degree of correction between variables.

4. Discussion

4.1 Relationship between plant composition and environmental variables

Using Canonical correspondence analysis (CCA) ordinations, the relationship between plant communities and environmental variables (edaphic factors) were assessed. Significantly correlated soil factors were available soil nitrogen, soil organic matter, calcium, sodium, and magnesium ions. An extensive data set of 241 plant species in 170 plots were used to explain the relationships. The proportion of variation analysed by the two ordination axes is 5.1%, which is very small. Nevertheless, many ecological data sets explain the percentage variation were less than 10% (Wiegleb & Felinks, 2001).

Soil, habitat types and vegetation are the immense conspicuous resources of valley bottom wetlands. Understanding variation in plant communities with location creates a platform to infer possible mechanisms of vegetation community assembly (Kadowaki *et al*., 2014; Yamaji, Honda, Hanai, & Inoue, 2016). The distribution of vegetation in the wetlands would also subsequently be affected by changes in ion and nutrient availability (White, 1979). Similarly, our studies found that the main factors influencing vegetation distribution were soil organic matter (SOM), available nitrogen (A-N), potassium ion (K^+), sodium ion (Na^+), calcium ion (Ca^{2+}), magnesium ion (Mg^{2+}), hydroperiod, human disturbances, and cattle grazing. Species in community one was primarily found in poor fen habitats and covered with sphagnum moss creating deposition of thicker peat, creating the slightly acidic condition (Smith, 1966) and ericaceous shrubs such as *Gaultheria nummulariodes* D. Don and *Rhododendron thomsonii* Hook. f. Plant species were associated with exchangeable sodium, calcium, magnesium ions and soil organic matter.

A strong correlation between SOM, $K^{+,}$ Na^+, Ca^{2+} and Mg^{2+} has been recorded in the community I. Similarly, the correlations were documented in the study conducted at Lake Taihu, China (Li *et al*., 2017). However, dwarf bamboo (*Yushania microphylla*) is abundantly (60%) present in the valley bottom wetlands, indicating better adaptation in different habitat types (ICIMOD & RSPN, 2014). Hydrology also influences the types of vegetation in a wetland (Mitsch, Gosselink, Anderson & Zhang, 2009; Rossi *et al.*, 2014) and tends to remain in a zone and adapt in anoxic or reduce conditions with a small number of species (Keddy, 2000; Corry, 2012). Plant communities in community type III usually thrive; a small number of seasonally inundated habitats and hydroperiod may be the influential factors for this community type. It remained waterlogged for a certain period. This finding is in place of results recorded in the wetlands study in the Eastern Himalayan Highlands, Gasa (Tendar *et al*., 2020). However, detailed studies on hydrological influence were beyond the study's scope and deemed deep necessary in the valley bottom wetlands in future. Species in community II are connected to drained habitats and close to anthropogenic activities and maximum cattle grazing areas with more weed species.

These results are pertinent to Arnold & Gibbons (1996) findings in which they revealed that overgrazing lowers the water table by increasing surface run-off. Some species such as *Hemiphragma heterophyllum* Wall., *Plantago erosa* Wall and *Rumex nepalensis* Spreng were slightly influenced by available nitrogen. Studies recorded disturbances by cattle grazing, faeces, and urine dropping into the soil enriched nitrogen and influenced plant community (Steven & Lowrance, 2011). Studies conducted at high altitude wetlands of northern Bhutan disturbances were based on the presence or absence of weed species (Tendar *et al*., 2020) and the prevalence of houses, roads, and agricultural activities (Lhamo *et al*., 2020) in the Gangtey-Phobji Wetland.

Anthropogenic activities and cattle grazing might disturb much of such a plant community. It might lead to the occurrence of many “weedy” herbaceous species in such a community (Harris *et al*., 2005; Xiong *et al*., 2003). However, invasive species *Trifolium repens* L. which overgrow and spread pervasively in the wetlands, were introduced as livestock fodder, and invasive species can significantly affect the native species' biodiversity and ecosystem functioning (Roder, Dorji, & Wangdi, 2007). Similar studies conducted by (Lhamo *et al*., 2020; Tendar *et al*., 2020) in the Gangtey-Phobi wetland and high-altitude wetlands in the Gasa, northern, Bhutan also recorded exotic species due to the disturbances. The purposeful introduction of exotic species for grazing has happened in many wetlands systems and is a possible threatening process to the Pantanal wetland in central South America (Harris *et al*., 2005).

Community II and IV observed not many differences in soil habitat with similar species in these communities. The possible reason could be owing to the exact location of sites. The most striking observation in those communities was the short vegetation in the higher level of grazing and closer to anthropogenic areas. In the Brazilian Pantanal wetland, a study performed by Miranda *et al*. (2018) also observed short vegetation. Species in this community were associated with available nitrogen compared to others and infer possible reasons for nutrient input by eutrophication from potato cultivation. However, (Lhamo *et al*., 2020) initiated a study in the Gangtey-Phobji Valley bottom wetland that obtained lower nitrogen content in the soil, close to higher anthropogenic activities locations that were contradictory with findings in this research. So, further studies are necessary to confirm the contradictory results.

5. Conclusions

The influence of plant community and distribution in the Gangtey-Phobji Valley bottom wetland were soil edaphic factors such as available nitrogen, soil organic matter (SOM), sodium, calcium, and magnesium ions. This paper also suggests other factors like hydrology, cattle grazing, and human disturbances as influencing factors that shape the few plant communities.

Gangtey-Phobji Wetland are amid human settlements with expanding agricultural activities and tourism development within the wetlands' hinterland, ultimately resulting in depletion and tremendous threats to wetland. Understanding and knowing factors affecting plant communities may help stakeholders, policymakers, and the government put the proper conservation measures for the sustainable use of wetlands in the country. Another pressing threat observed in the wetlands were intensive cattle grazing and could not address comprehensive details in the paper as it were beyond the study's scope. Further study to gain and enhance ecological knowledge of the Gangtey-Phobji Wetland is highly recommended.

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