Scientific Discourse of Lakes in Nepal

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Abstract
Over 5,000 standing water bodies, including those <1 ha and spread in 74 districts of Nepal have been scanned on the topographic sheets (scale of 1:125,000). Majority of these lakes or ponds are either in the high altitudes (above 3,000 m) or in lowland Tarai (below 500 m). In a literature review we found over 163 research studies conducted since the first study of lakes in 1969 in Khumbu region, majority being at the initiative of national academia, their faculties and graduate students. However, a complete inventory of Nepal’s lakes is still lacking. Their characteristics and distinction from wetlands are also to be defined as the existing laws and rules do not protect lakes or ponds categorically, rather they are blanketed under wetlands and/or other river like water resources. Research observations have shown that acid depositions are the most likely source of pollution affecting high altitude lakes in the Himalayan regions during spring. Their value as religious sites has also caused anthropogenic alteration in nutrient concentrations and biological assemblages of the lake. Encroachment to the lakes/ponds is rampant to which the natural processes of sedimentation, alien species invasion or any kind of obliteration become supportive. Capacity building, knowledge generation and threat management are vital to protect these natural heritages from untimely demise.

Key words: biodiversity, conservation, geographic coverage, socio-economic values, water bodies

Introduction
In Nepal, water bodies cover 5.06% of the total land area (FDD 1992). Of the estimated coverage of 720,000 ha of these water bodies, some 3.2% is occupied by lakes including ghole, ponds and reservoirs. The rest are river systems and paddy fields. Lakes and ponds play important role as wintering habitat and stoppage for a wide variety of migrant birds which cross the Himalaya on their way between breeding places in north and central Asia and wintering places further south in the Indian sub-continent (Scott 1989). In Nepal, about one fourth of its total biodiversity (estimated 6,500 vascular plants) is reported to be related to wetland and/or lakes (Bhandari 1992). The Nepali lakes are of natural as well as artificial, such as glacial and tectonic origin in the mountains or oxbow lakes in the lowlands, and man-dug near settlements. Lakes hold multi-purpose values in Nepal and Nepali society. The majhis (fishermen) make livelihood out of the lake resources such as fish, while those dwelling in the lake vicinity directly use its water for drinking purposes and also for irrigating their agricultural lands. Every year, thousands of pilgrimage throng to high mountain lakes (e.g., Gosaikunda), and no less number of people celebrate Chhath dipping in the lakes in lowland Terai (e.g., Janakpur). Lakes play a vital role in national economic activities as they have been tourist destination (e.g., Pokhara). Many cities and settlements, where natural lakes do not exist, have maintained ponds; for example a small city Janakpur (area: 24.6 sq km) in Nepal Tarai has at least 45 ponds (Singh 2002).
Bhuju et al. (2009) prepared a list of 5,358 lakes using the topographical sheets (total 706 sheets) encompassing Nepal’s territory (area: 147,181 sq km). Of the 75 districts, 74 consisted of lakes of varied size, from less than 1 ha to 800 ha (Rara Tal in Mugu). Four districts contained over 300 lakes in them, viz. Humla (381), Taplejung (380), Kapilbastu (351) and Solukhumbu (339). Altitudewise, over 2,700 (51.0%) were found to be distributed below 500m, and 2,227 (42%) above 3,000m. Only 419 (<8%) were in the mid hills of altitudinal range between 500m and 2,999m. The lowest altitude lake inventoried was in Dhanusha (unnamed, alt. 59m asl), and the highest altitude lake was in Mustang (Dhau Dhun Tal, alt. 5,905m asl). District Okhaldhunga is reported without a lake.

Objective
The objective of the present study was to understand the scientific discourse and priorities of various researches conducted on lakes and ponds of Nepal.

Methodology
We collected literature on studies of the lakes and ponds in Nepal conducted by various researchers, both through national and international efforts. The collected data span for four decades from 1960 to 2010. The studies were categorized by physiographic coverage denoting various ecological zones, their study scope and findings. The findings of the studies were analyzed by major priority areas such as biodiversity conservation, water quality analysis and pollution, cultural and management, etc. Based on the available information, we also listed some threats and suggestions.

Findings and Analysis
Lake definition
There is considerable uncertainty about definitions of lakes and distinction between lakes and ponds. Limnologists have defined lakes as water bodies that are simply larger versions of ponds, or that have wave action on the shoreline, or where wind-induced turbulence plays a major role in mixing the water column. In Nepal, a general terminology to denote lake in Nepali language is Tal (pronounced Taal, e.g., Phewa Tal) which generally refers to large water bodies of natural origin. Beside this, there are few other synonyms derived from Sanskrit such as Kunda (e.g., Gosainkunda), Jalasaya, Sarowar, Talau. A commonly used terminology is Pokhari, which generally means smaller water bodies of natural (e.g., Kanepokhari) as well as human made (e.g., Ranipokhari). The other terminologies to denote water bodies are Daha, Kiewa. Local communities use their own terminologies for lakes/ponds, examples, Pukhu (Newar), etc. Regardless of their definition and/or varied names, all kinds of water body have their role as habitat for myriad of organisms and do contribute in the ecosystem energetic.

Publications
Till 2010, 163 publications including masters’ degree thesis on the study of lakes and ponds in Nepal were listed from various sources of information (Bhuju & Gaire 2010). Besides these, 40 reports based on district level consultation and lake survey conducted by Nepal Academy of Science and Technology (NAST), National Trust for Nature Conservation (NTNC) and Central Department of Environmental Science, Tribhuvan University (CDES/TU) with support from National Lake Conservation Development Committee, Government of Nepal have been prepared. Of the total publications referred, 83% were based on scientific objectives, mainly on water quality, fisheries and limnology (Fig. 1).

Fig. 1. Different aspects of research on lakes of Nepal

The first literature related to lakes of Nepal was the one by Löffler in 1969. He explored 24 high altitude lakes located at the altitude of 4,500 m – 5,600 m asl in the Mount Everest region, and reported the first data on morphometry, temperature, chemistry and biology (Löffler 1969). During 1970s, the number of studies was eight, which increased to 20 during 1980s. During 1990s, the number of studies reached 58, particularly from Tribhuvan University. During 2001-2009, 76 studies on lakes and ponds had been conducted by various researchers (Fig. 2). Among scientific studies, 35 were Master degree theses in different disciplines of science mainly botany and environmental science. Ten percent of the studies had their management
Physiographic coverage
Nepal boasts lakes of varied ecological conditions from subtropical lowland Tarai to high altitude alpine providing opportunities for wide array of studies. By physiographic zones, majority of Nepal’s lakes and ponds are located in the high altitudes (51%) and lowland (42%), but much of the studies conducted so far were in the middle mountains, where 82 studies were carried out covering 50.3% of the total studies on lakes in Nepal (Fig. 3). Among the studies carried out in the middle mountains, most of them were in Pokhara and Kathmandu valley. There were 41 studies conducted in Churiya-Terai region. From the remote high mountains, 21 publications were listed, half of which were based in Mount Everest region. Thus, there exists a stark discrepancy in the lakes studies in Nepal, which could be because of geographic remoteness and resource constraints. Of the total studies, majority (76%) was conducted by Nepali researchers, 15% by foreigners and the rest jointly by Nepali and foreign scientists (Fig. 4).

As the lakes have been religious and pilgrimage sites for many communities in Nepal, research study scope has extended to their socio-cultural values and conservation aspects. IUCN (1998) listed over 20 lakes and ponds that are considered very holy by various religious groups. The cultural importance of the lakes have been studied and reported by Baral (1992), Bhandari (2005). Recent studies on lakes have included listing the important dates of cultural/religious events (Adhikari 2009, Aryal 2009, Neupane 2009, Khadka 2009). On the conservation management and local

Fig. 2. Studies on lakes in Nepal 1961-2010

Fig. 3. Studies on lakes by physiographic zones in Nepal

Fig. 4. Proportion of researchers on lake studies in Nepal

Study scope
knowledge, the works by Shrestha (2004), Gurung et al. (2005), Wagle et al. (2007) are worth mentioning here.

Lakes in high mountains
Aizaki (1985) studied trophic status and water quality of Lake Tilicho in Central Nepal Himalaya. The lake is one of the largest glacier-fed lakes with slightly turbid water color and strong chemical stratification. This study revealed a low concentration of total phosphorus (1–6 mg/l) and total nitrogen (0.16 to 0.25 mg/l) in water. The chemistry of 31 lakes at altitudes between 4,530m and 5,480m asl in the Khumbu and Imja Khola valleys was considered, around a third of which was reported to have Na+ and Cl– of marine origin transported by the summer monsoon (Tartari et al. 1997). Three groups of lakes with different levels of ion concentrations and silica were highlighted using cluster analysis. Palaeo-limnological analyses of four Himalayan lakes (Piramide Superiore, Piramide Inferiore, Lake 40 and Lake 70) were carried out in the Everest region. Despite being characterized by very slightly polluted chemical conditions, the sedimentary record of phytoplankton and benthic algae in lake Piramide Inferiore and Lake N. 40, showed that there have been periods of high productivity.

Rara, which is the biggest natural lake of the country, lies at an altitude of 2,990m asl in far western Nepal, and it has only one outlet that joins the river Karnali. Thermocline in this lake was visible below 14 to 50m and temperature was recorded as 7.5 to 7.6°C (Ferro 1978, 1979). Similarly, the morphology, physics, chemistry and biology of the lake were studied, and high level of pH, conductivity and total hardness was reported. The lake was classified as oligotrophic in limnological terms (Okino & Satoh 1986). studied on.The impacts of global climatic change on biodiversity of high altitude lake Gokyo in Everest region was studied recently (Sharma et al. 2009).

Lakes and ponds in Kathmandu valley
It is said that Kathmandu valley was a big lake, and a legendary Manjushri drained it at Chovar gorge for the settlement. Natural lake as remnant of this is represented by Taudah near the gorge. Various biological components including phytoplankton and physicochemical parameters of water samples of Taudah pond in Kathmandu valley have been studied by Hickel (1973), Bajracharya (1982), Acharya (1997), Bhatta (1997), and Acharya (2003). A more detailed investigation on chemical aspects of Taudaha and Nagdaha – the largest ponds in the valley was performed by Lohman et al. (1988), Jones et al. (1989). Similarly, ponds in Kirtipur and Bhaktapur have been studied both chemically and microbiologically (Joshi 1979, Parajuli 1997)), and these studies reveal high levels of chloride and phosphate as well as coliform bacteria.

Lakes in Pokhara valley
Pokhara valley contains several lakes, the most popular are: Phewa, Rupa, Begnas and Khaste, which finally drain their water into the Saptagandaki river system. These lakes are well studied compared to other regions. Temperature, transparency, electrical conductivity, pH and alkalinity of the lakes were investigated followed by species composition, vertical distribution and seasonal variations of phytoplankton (Hickel 1973b). Three major lakes (Phewa Tal, Begnas Tal, and Rupa Tal) were investigated in two seasons to examine the influence of monsoon on their limnological conditions (Lohman et al. 1988). Calcium concentration in Phewa Tal accounted for 66.3% of the cation and 43% in Begnas Tal and Rupa Tal; anions were predominantly bicarbonate in all three lakes. The most complete limnological investigation was carried out in Nepal in 1989, in which 50 lakes were surveyed, including the lakes from Pokhara Valley (Jones et al. 1989). Rai (2000) studied and analyzed limnological characteristics in three lakes of Pokhara (Phewa, Begnas and Rupa) from 1993 to 1997. The water temperature ranged from 12 °C to 29 °C in all lakes.

Lakes in Churiya-Tarai region
The wetland list prepared by IUCN (1992) mainly included lakes and ponds from the lowland Terai of Nepal. Devital, Lamital and Tamortal were investigated in Chitwan National Park and classified as oligotrophic. Limnological work on the lakes of far western region of Nepal is limited (Metcalf & Eddy 2000). Bhuju (2004) recorded some lakes in the dry lands of Churiya hills and highlighted their importance. Recently, Adhikari (2009), Neupane (2009) and Khadka (2009) studied the water quality and surrounding vegetation of dryland lakes of Churiya hills in far western Nepal, viz. Jhilmila, Betkot and Mudka Tal. Studies were carried out in Beeshhazari Tal in Chitwan (Jayana 1997, Burlakoti & Karmacharya 2004), Ghodaghodi in Kailali (Baral 1992, Acharya 1997). The compositions of benthic macroinvertebrates of two ponds in Mahottari district were studied by Mahato & Yadav (1984), and 31 taxa were recorded, and the pond was classified as eutrophic.
Table 1. Common flora and fauna in wetlands of different physiographic zones of Nepal

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<th>Physiographic zones</th>
<th>Flora</th>
<th>Fauna</th>
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<td><strong>High Mountain</strong></td>
<td>All the glacial lakes are devoid of macro aquatic vegetation. The dominant aquatic flora are: reed (Phragmites sp.), rushes (Juncus sp.), sedges (Fimbristylis sp.) in the littoral zone, and Myriophyllum sp. in shallow water. Other species include Potamogeton mestis, Oxygaphis polypetala and Ranunculus sp.</td>
<td>No fauna have been reported so far from the glacial lakes. In freshwater tectonic lakes harbor some fauna. <strong>Mammals</strong>: Smooth otter (Lutra perspicillata), Vole (Pitymys sanneni), alpine voles (Apodemus fuscus), gharial, The bar water shrew (Helosciurus lagopus). <strong>Birds</strong>: Bar headed goose (Anas indicus), the black (Tadorna ferruginea), common teal (Anas crecca), mallard (Anas platyrhynchos), crested pochard (Aythya fuligula).</td>
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<td><strong>Middle Mountain</strong></td>
<td>As the water is in mesotrophic and eutrophic state, vegetation are comparatively richer than high mountains. The most abundant aquatic plants of this region comprise: Alternanthera sessilis, Ceratophyllum demersum, Cyperus difformis, Ceratophyllum crassipes, Frasconoto nepalensis, Hydrilla verticillata, Lacinia pedunculata, Mannisus samatranus, Monochora vaginalis, Myriophyllum sp., Najas sp., Nymphoides officinalis, Nymphoides sp., Nymphoides indicus, Paracaria sp., Polygonum hydropiper, Potamogeton cristatus, P. pectinatus, Ranunculus: arvensis, Rumex sp. Scirpus articulatus, Sporobolus poicifolius, Trapa bispinosa, Utricularia sp., Vallisneria sp., Wolffia sp., etc.</td>
<td><strong>Mammals</strong>: Smooth otter (Lutra perspicillata), small clawed otter (Aonyx cinerea), fishing cat (Felis viverrina). <strong>Birds</strong>: Pied kingfisher (Ceryle rudis), coot (Fulica atra), purple moorhen (Porphyrio porphyrio), brown winged tattler (Tringa melanoleuca), teal (Anas crecca), Ringed plover (Charadrius hiaticula), Cattle egret (Bulbulus ibis) common night heron (Gallinago gallinago), Mergell (Anas platyrhynchos) Pond heron (Ardea grupeg).</td>
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<tr>
<td><strong>Lowland</strong></td>
<td>As the water is in mesotrophic and eutrophic state, vegetation are comparatively richer than high mountains. The most abundant aquatic plants of this region comprise: Alternanthera sessilis, Ceratophyllum demersum, Cyperus difformis, Ceratophyllum crassipes, Frasconoto nepalensis, Hydrilla verticillata, Lacinia pedunculata, Mannisus samatranus, Monochora vaginalis, Myriophyllum sp., Najas sp., Nymphoides officinalis, Nymphoides sp., Nymphoides indicus, Paracaria sp., Polygonum hydropiper, Potamogeton cristatus, P. pectinatus, Ranunculus: arvensis, Rumex sp. Scirpus articulatus, Sporobolus poicifolius, Trapa bispinosa, Utricularia sp., Vallisneria sp., Wolffia sp., etc.</td>
<td><strong>Mammals</strong>: Frog (Rana lessoniana, R. indicus, R. himalayana), Himalayan mouse (Tylototriton verrucosus). <strong>Fish</strong>: Mountain trout (Schizothorax richardsoni), copper mahseer (Acrorhynchus kazirangoensis) and golden mahseer (Torga mahseer). <strong>Others</strong>: Stone fishes (percidae, plopholid). Myctylus (coenioids-Ceunis sp.), leptonychids-Epomus ruddia, Rhinotogenes nepalensis, parichthys-Balist (Epomus sp., Balsestella sp.), Cattley (Acrorhynchus kazirangoensis), Malaruca (unionids, pacudoids, physide-Phya sp.), Diptera (Simulidae, psocomyids, tabanids, chronomysidae), Crabs (pomatomidae).</td>
</tr>
</tbody>
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Reference:
- Ferno 1979
- Scott 1989
- Lohrer 1969
- Shrestha, T.K. 1994
- Shrestha, F. 1994
- Mee et al. 2005
Lakes and biodiversity
It is estimated that nearly one fourth of Nepal’s biodiversity occurs in wetland/lake dependent (Bhandari 1992). The occurrence of lakes and ponds in diverse ecological zones have made it rich in flora, thus, supporting significant number of aquatic and/or fresh water dependent fauna (Jha & Lacoul 1998). Table 1 consists common flora and fauna found in wetlands of three different physiographic zones of Nepal, viz. High Mountains, Middle Mountains and Lowland Terai. The High Mountains include mainly glacial lakes and tectonic lakes such as Rara, Phoksundo, Tilicho and Gosaikunda. They are oligotrophic and contains less diversity of flora with reed and sedges. The glacial lakes are almost free from fauna; however, the tectonic lakes contain some mammals (e.g., smooth otter, vole), birds (e.g., bar headed goose, shelduck, etc.), amphibians (e.g., Himalayan toad), and fishes (e.g., snow trout). The lakes of Middle Mountains are generally of tectonic origin and rain-fed. The water is mesotrophic or eutrophic, and is comparatively rich in flora and fauna. The lowland Terai contains rivers with flood plains and ox-bow lakes, and they are mesotrophic or eutrophic with rich biodiversity.

Threats and Issues
Anthropogenic impacts on lakes are spreading in most parts of the world and becoming more intense in quantity and quality due to increased human population and their activities. The high rate of deforestation and use of pesticides and fertilizers have spurred the spread of invasive species (Ayres et al. 1996, French 2000). Direct human influence is mostly absent in remote aquatic systems in the high Himalaya; however, anthropogenic activities are intense in midland and lowland and lead to eutrophication, pollution and degradation of water bodies particularly in urban and agricultural areas (Pandit 1999, Rai 2000, Thapa & Weber 1995). Diversion of lake water for use

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**Lakes and biodiversity**

| Low lands and Terai | Mammals: Wild buffalo (Bubalus bubalis), Otter (Lutra perspicillata), Game: dholes (Cuon alpinus), fishing cat (Felis viverrina) | Birds: Sow (Mergus albellus) RED bearded reed geese (Gallinago gallinago), Pacific golden plover (Pluvialis fulva), Spot billed pelican (Pelecous philippinus), Swamp pordige (Francolinus gularis), sarus crane (Grus antigone antigone), Rep: Gharial (Gavialis gangeticus), Mangrove (Crocodylus palustris), Tur (Trionyx gangeticus), water snake (Natrix piscatorius), Amphibians: Common toad (Bufo bufo), bullfrog (Lithobates larva), Fishes: Barbatula (alkaopora), Mystus vitatus, Amphillognus cincin, Heteromastera fossilis, Labeo rohita, Tor tor, Pandacephalus eurystoma, etc., Others: Mayfishes (hepgamidae), ephemeridae-Elphanta spp., Birsidae-Baetis spp., Caddisflies (hepgamidae), Brachycentrus spp., Palingenia-longipinnia spp., M. bucha (planocladus pleuroceridae-Broti sp., thekis, vivaiparous, amphibians, unionids), Dytira (psychodidae chironomids) |

Modified from Jha and Lacoul 1998

In Nepal, there are multiple threats to standing freshwater ecosystems. These include phenomena which occur naturally due to highly dynamic processes linked to geographical characters such as geomorphology and climatic conditions, in particular erosion, transportation, sedimentation and other hydrological changes. During the last decades many lakes and ponds in urban areas have been either degraded or disappeared due to expansion of settlements, heavy abstraction of groundwater and intensification of agriculture (Jha 1992). Many of the ponds are facing extinction, especially when they are in proximity to human settlements. Large numbers of ponds are either in the process of being overgrown by invasive plants due to management apathy.

Despite their great historical and cultural significance, potential economic value and importance for conserving aquatic biodiversity, ponds, lakes and other freshwater ecosystems in the Kathmandu valley are subjected to pollution and habitat degradation (Jüttner et al. 2003). Simkhada (2007) reported that many of the investigated ponds and lakes in covering high Himal, Midhills and lowland Tarai, are used inappropriately such as washing, dumping of litter and receive pollutants from drainage pipes, surface runoff and air pollution. Lakes in the high altitudes, such as Gosainkund are at risk of acidification, eutrophication, etc. due to their geology composed of base-poor bedrock.

Climate related changes such as altered levels of UV radiation and temperature, and the rising atmospheric pollution over the Indian sub-continent is also seen as threat which may have significant effects on sensitive ecosystems. Findings suggest that acid depositions are the most likely source of pollution at present affecting high altitude lakes in the Gosainkund area during spring (Simkhada 2007). Their value as religious site has also caused human originated alteration in nutrient concentrations and biological assemblages of the lake. The need for further investigations to assess consequences of long distance transport of atmospheric pollutants and other anthropogenic impacts for these sensitive ecosystems has been stressed by some authors (Lami et al. 1998, Tartari et al. 1998). Melting of glaciers in high altitude lakes also pose serious threat (Bajracharya et al. 2007).

Altogether 278 lakes lie inside the protected areas, i.e., less than four per cent of the total lakes in Nepal. While many of these studies focus on water quality (physical, chemical and microbial) of lakes, studies on their structural properties such as morphometry, bathymetry, hydrology, limnology and ecology are very limited. Survey and mapping of lakes to prepare their national inventory and resource contents, land-use history, land ownership, lake-ontogeny, and terrestrial biodiversity influencing the lake ecosystem are almost non-existence. This, on the positive note, indicates that there is high opportunity of unveiling new findings from the scientific studies of lakes and ponds in Nepal.

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Bhattarai, B. 2008. Seasonal changes in water quality parameters and sediment nutrients in


