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Vollenweider Model for Temporal Eutrophication Characteristics of Nagdaha Lake, Nepal

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Abstract: The study was carried out in Nagdaha (about five kilometres away from Lagankhel), Dhapakhel VDC, Lalitpur (between 27°37′53″ N and 85°20′2.8″ E at an altitude of 1340 m), Nepal. The status of trophic characteristics of the Nagdaha was calculated on the basis of normalized average phosphorus $[P]_\lambda$ and chlorophyll $[Chl]_\lambda$ through verified Vollenweider Model. The water quality parameters like pH; nitrate, total phosphate and alkalinity; temperature and dissolved oxygen were tested for the assessment purpose. The measurement of lake depth was done through depth sounding method where GPS co-ordinates were recorded, then analysed, managed and presented using GIS for bathymetric map. The area of lake as given by aerial photograph was determined to be 3.07 hectares; while various litreatures enlisted the area as 2.65-5 hectares. The bathymetric map area calculation entailed that the area was 2.51 hectares (decreased by 500 square metres). The depth of the lake varied from 0.30 metre to 4.70 metres. The residence time, in which mean depth of water body act as vital role in resulting various trophic level. The lake was hypereutrophic and eutrophic at average phosphorus loading up to first 2.5 metre and onward depth respectively. The normalized phosphorous and chlorophyll concentrations during winter were found greater than in summer seasons.

Key words: GIS, bathymetric, residence time, hypereutrophic.

Introduction

Eutrophication refers to the excessive nutrient enrichment of water which results in an array of undesirable symptomatic changes (OECD, 1982), including nuisance production of algae and other aquatic plants, deterioration of water quality, taste and odour problems and fish kills. High loading of nutrient causes turbid state stable, whereas opposite is true for low nutrient loading in which both states may exist in intermediate state (Janse et al., 1998). Eutrophication and deterioration in water quality, siltation and consequent swallowing and shrinking of lakes are major problems and are assuming alarming proportion in aquatic ecosystem (Vijayvergia, 2007). Eutrophication of aquatic body ranks as one of the most pervasive water quality problems around the world and can have significant negative ecological, health, social and economic impact on human's use of primary and finite resource (Rast et al., 1989).

Occasionally, the N to P ratio is still used by some investigators alone for determining the limiting nutrient. In U.S. OECD eutrophication however, principal consideration was made that maximum summer algal biomass in the water body be limited by phosphorus (Rast et al., 1983). While studying the eutrophication, it is more important to consider relationship between hydraulic and chemical residence time. It was also

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considered that there should be at least two weeks (0.04 year) hydraulic residence time to allow algae to grow. Generally, the chemical residence time of a conservative chemical is same as its hydraulic residence time; for a non-conservative chemical like phosphorus, the chemical residence time is shorter than water residence time. It is the residence time of phosphorus in the water body that governs the response time to change in phosphorus load (Rast et al., 1983). It was found that the phosphorus residence time generally decreases as the degree of eutrophy increases based on U.S. OECD data (Rast and Lee, 1978).

Nepal is home to a wide range of wetlands situated in diverse climates, stretching from mountain condition near the Himalayas in the north to tropical condition in the south. The total area occupied by wetlands has been estimated to be 3827 square kilometres covering approximately 2.6% of total land area of Nepal (GoN/MFSC, 2009). Lakes and wetlands are important features of Earth's landscape which are not only the source of precious water, but provide valuable habitats to plants and animals, moderate hydrological cycles, influence microclimates, enhance the aesthetic beauty of landscape and extend many recreational opportunities to human kind (Sharma et al., 2010). Because of eutrophication, they are losing their original characteristics; as a result aquatic lives get threatened and water becomes unsuitable for any kind of use. It has been reported that the various eutrophication levels exist as 53%, 28%, 48%, 41% and 54% of lake in Europe, Africa, North America, South America and Asian Pacific area respectively (Zang et al., 2011).

During 1960-70s, a number of researches have been conducted to evaluate the trophic status of lakes quantitatively through using single-variable trophic indices or multi-parametric approaches (Vollenweider, 1968, 1976). It is a fact that OECD eutrophication modelling approach has been found applicable to approximately 300 water bodies evaluated to date (Rast et al., 1983). In this study, Vollenweider model was used as lake management model to find out the trophic characteristics of Nagdaha for the winter and summer seasons in terms of total phosphorous rather than classical nutrient (nitrogen, phosphorous and potassium) parameters as practiced elsewhere in Nepal. The result obtained from this model was compared for the temporal analysis of trophic characteristic of the lake. Bathymetric map was prepared to know scenarios trophic level in various depths for eutrophication process. The specific objectives of the study were to find out the trophic characteristics of Nagdaha lake in winter and summer seasons in terms of total phosphorous by using Vollenweider Model and to assess fundamental water quality for the prediction of free aquatic life survival in reference to selective water quality parameters.

Methods and Materials

Study Area

Nagdaha lake (Figure 1) is one of the historically and culturally important spring shallow lake in Kathmandu Valley, Nepal located at south to the Valley at Dhapakhel VDC-8, Lalitpur district. Geographically, it is extended between 27°37′53″ N and 85°20′2.8″ E at an altitude of 1340 m. It was believed that the area of lake was about many square metres (http://ecs.com.np/features/nagdaha-a-visit-to-the-snake-lake) with many metres of depth lies to southern region of Lalitpur district, about five kilometres away from Lagankhel. Besides the historical and cultural importance of lake, it is one of the tourist destinations in Kathmandu Valley. The lake is habitat for the different types of fishes, snakes and other macrophytes. The lake is surrounded by agricultural land, number of hotels and restaurants and aqua cultures. More importantly, the commercial and agricultural activities from the surrounding villagers, urbanization, siltation and eutrophication process have been matter of concern for de-sizing of lake area and deteriorating natural water quality. In addition, these natural and anthropogenic activity minimizes the historical and cultural values of the lake namely Akhidaha since the major source of water for this lake is Nagdaha. Moreover, the lake is a major source of water that has been utilized by surrounding villages for washing, bathing, irrigation and livestock feeding. So it is important to manage and protect its historical, cultural and natural beauty for benefits of local people in sustainable way.

OECD Management Model

OECD eutrophication model was described in detail by Rast and Lee (1978) and Vollenweider and Kerekes (1982). Jeppesen et al. (2005) also used an equation developed by Vollenweider (1976) and OECD (1982) to analyse the phosphorus loading concentration. The OECD management model synthesizes the standard equations for the relationships between average phosphorous concentration $[\bar{P}]_f$, expected average lake concentration $[\bar{P}]_\lambda$ and expected average chlorophyll $[\overline{Chl}]$ concentration as a function of the average water residence time (τ_w). OECD (1982) regressions above need the water residence time, which in turn would imply mean depth. Water residence time (τ_w) was calculated with area multiplied by specified depth divided by total volume of water. In many cases, mean depth of lakes are not available, in which this model may be used with the appropriate trophic categories, preferably the OECD (1982) management model plotted on graphs. The long-term correlation equations are proposed for plotting the trophic characteristic graphically. The model is based on the calculation of critical loading of phosphorous (L_c) from critical total phosphorous concentration (P_c^{sp}), mean water depth (z) and water residence time (τ_w) in which (z/τ_w) regarded as hydraulic load (q_s).

Critical phosphorus loading,

$$L_c(\text{mg m}^{-2}\text{y}^{-1}) = P_c^{sp}(z/\tau_w + 10) \quad \text{(i)}$$

Normalized phosphorus loading,

$$[\bar{P}]_f = 1.81(L_c/q_s)^{0.81} \quad \text{(ii)}$$

Average phosphorus loading,

$$[\bar{P}]_\lambda = 1.55([\bar{P}]_f/1+\sqrt{\tau_w})^{0.82} \quad \text{(iii)}$$

Average chlorophyll, $[\overline{\text{Chl}}] = 0.28[\bar{P}]_\lambda^{\,0.96}$ (iv)

Water Sampling

The water samples were collected during winter (2011) and summer seasons (2012) from lake following the standard operating procedures (ISO, 1987). On the basis of activities and nature of the lake, five sites (Site 1: Centre; Site 2: Northern corner; Site 3: Western corner; Site 4: Southern corner; Site 5: Eastern corner with GPS coordinates) were selected randomly for the assessment. The overall sampling process was depth integrated sampling in which mixed volume samples integrating identical portions of the total amount taken as grab samples at different depth intervals, so that the integrated sample gives average concentrations for the whole depth column. Due to enough depth at Site 1, the sample collected from different depths (surface, mid and bottom) were tested in order to know the variation of dissolved oxygen content. The temperature was also measured in Site 1 (centre) from various depths, while nitrate, total phosphorus and alkalinity were calculated from surface water samples at each site. The water quality parameters were analysed in the accredited laboratory, Nepal Environmental Scientific Services (NESS) and Golden Gate International College's lab by following the procedures as given by standard methods for water and wastewater analysis (APHA-AWWA-WPCF) (Clesceri et al., 2005). Based on the maximum and minimum values of total phosphorus selected from each site representing whole lake, the limiting average phosphorous level was undertaken using Vollenweider model and assigned for the calculation of normalized phosphorous and chlorophyll calculation using above mentioned equations (i), (ii), (iii) and (iv) accordingly.

Data Analysis

The variables like total phosphorous, area and depth were used in the model fit parameters and trophic characteristics (Janse et al., 1998) were calculated by the application of model. Correlation analysis was carried out for statistical analysis of data. Similarly, majority of excel graphs were drawn for the required graphical justification. The water quality data were weighed against respective water quality standards and guidelines (GoN/MFSC, 2009) for aquatic life survival, irrigation water quality, etc. Different litreatures, aerial photos (1979) and topographic map (1996) interpretation envisaged that the area of lake had been decreasing. In this study, the rate of decrement of lake area, depth and water volume at the current time was estimated with generation and interpretation of bathymetric map of lake prepared with the help of depth sounding method for measurement of depth and recorded the co-ordinates for each point using Global Positioning System (GPS). These captured data were analyzed, managed and presented using Geographical Information System (ArcGIS version 10) for final bathymetric map. The lake bathymetric map was used for an illustration of trophic level at various depths of lake for eutrophication process.

Results

The depth of lake varied from 0.30 metre to 4.70 metres. The bathymetric map (Figure 2) illustrated that the lake had the total area coverage of 25,080.68 square metres and maximum depth of 4.7 metres with total volume of water 117,879.208 cubic metres. The area of the historic lake measured by aerial photograph was determined to be 30,400 square metres, while that from various litreatures was 26,500 square metres and is between 30,000 to 50,000 square metres (Stanners, and Bourdeau, 1995). The consultant (based on dialogue) of Nagdaha Conservation and Improvement Committee argued the existing area of lake was about 21,400 square metres. On the basis of previous studies and recent aerial photograph basis, 500 square metres have decreased the area of the lake.

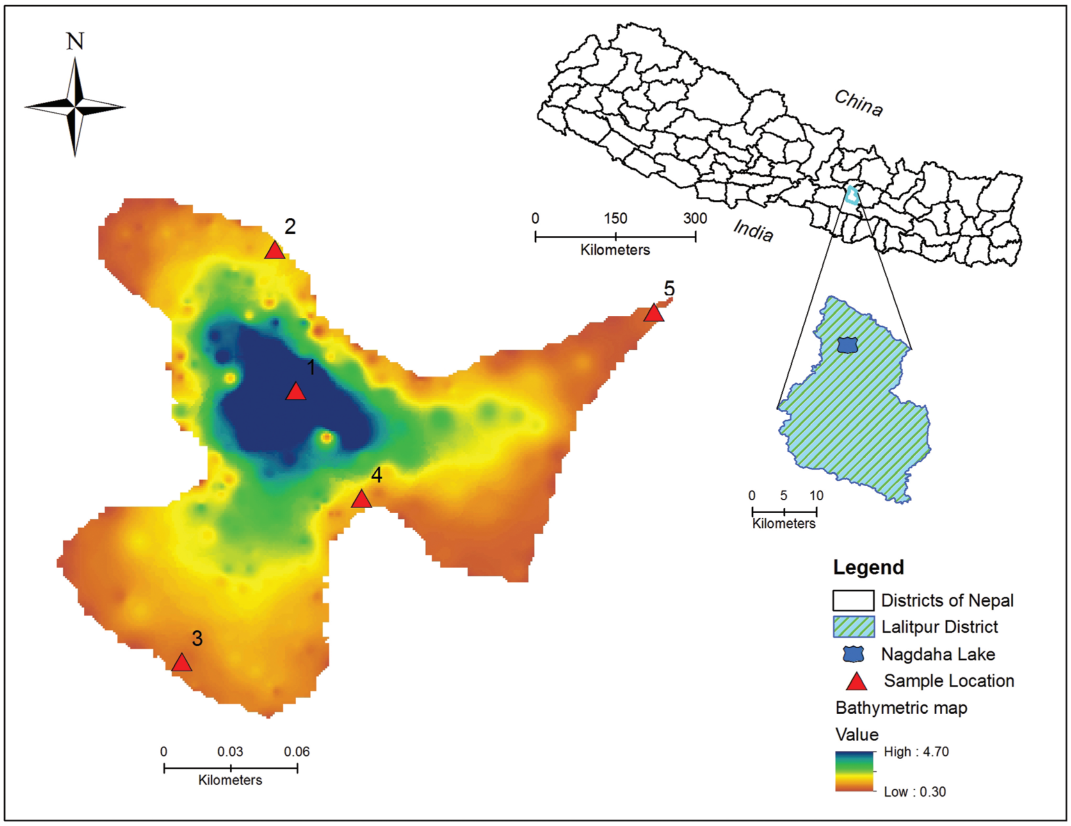


Figure 1: Study area with sample sites.

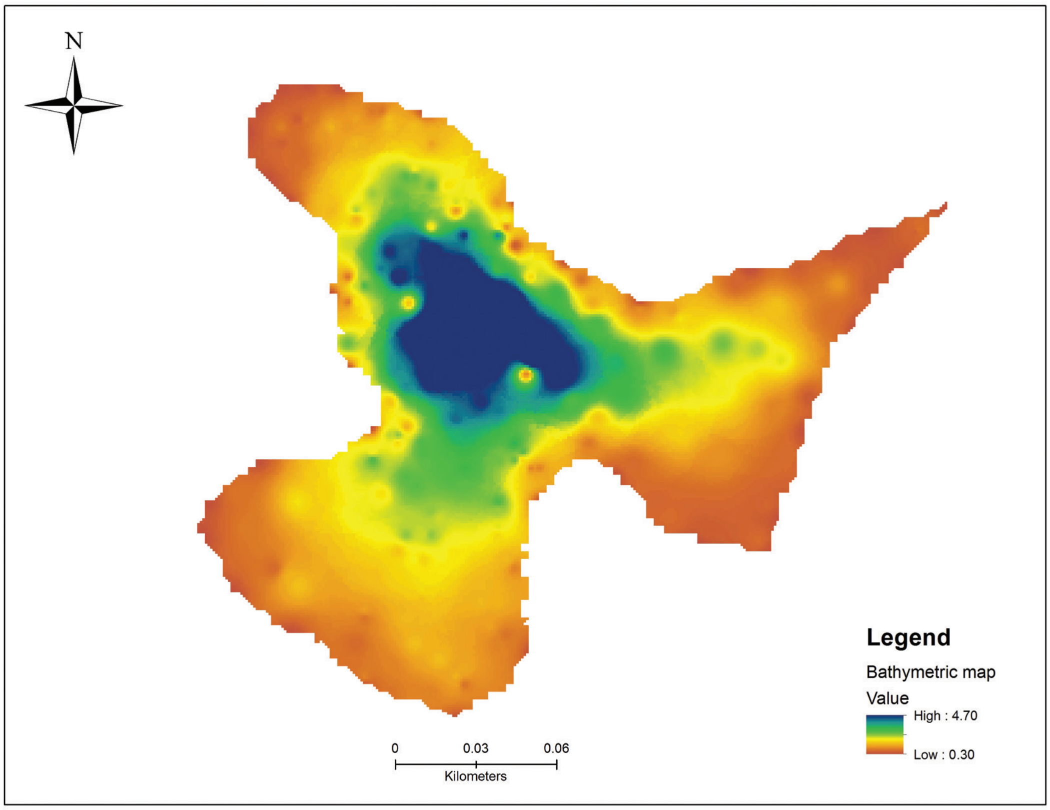


Figure 2: Bathymetric map of Nagdaha Lake

The chemical parameters test revealed that the observed values of nitrate at Site 4 were found higher for winter (3.99 milligram/litre) and summer (2.73 milligram/litre) seasons than other sites (Figures 3a and 3b). The total phosphorous concentrations in the studied sites ranged from 0.12 milligram/litre to 0.24 milligram/litre in winter whereas it was minimum (0.04 milligram/litre) at Site 1 and maximum (0.11 milligram/litre) at Site 3 in summer season. Except at Site 1 in winter, the observed total alkalinity values exceeded 25 milligram/litre for all seasons. The depth-wise temperature variation was found within two degrees Celsius for both seasons.

The lake water was nearly at neutral condition where the average pH value for winter and summer seasons were 7.8 and 7.4 respectively (Table 1). The analytical water quality data entailed that the average concentrations of total alkalinity, nitrate and total phosphorous were slightly higher in winter than summer seasons. But, the average dissolved oxygen concentration was found slightly lower in summer and was at critical level (<5 milligram/litre). The calculated oxygen saturation percent for bottom (4.7 metres), mid (2.35 metres) and the surface were 19, 36 and 45 only in winter season whereas they were 13, 22 and 45 respectively (Figure 3c) in summer.

With consideration of maximum phosphorous level, it is calculated that average seasonal normalized phosphorous (PO_4-$P[P]_\lambda$) load ranged from about 42.17 milligram/cubic metre/year to about 95.91 milligram/cubic metre/year whereas normalized chlorophyll, $[Chl]_\lambda$, varied from about 10.17 milligram/cubic metre/year to about 21.17 milligram/cubic metre/year respectively for summer season. The Vollenweider model calculation depicted that the lake showed hypereutrophic characteristics up to about 1 m depth and eutrophic for lake depth 1 m onward at minimum average phosphorous loading (Table 2) for the same season. Similarly, the average seasonal normalized phosphorous (PO_4-$P[P]_\lambda$) load ranged from about 70.17 milligram/cubic metre/year to about 151.98 milligram/cubic metre/year whereas normalized chlorophyll, $[Chl]_\lambda$, varied from about 16.72 milligram/cubic metre/year to about 34.81 milligram/cubic metre/year respectively (Table 2) for winter season. At maximum phosphorous loading condition, the lake showed hypereutrophic characteristics up to about 3.5-metre depth and eutrophic for lake depth 3.5 metres onward for this season.

Based on the minimum phosphorous level, it was calculated that average seasonal normalized phosphorous (PO_4-$P[P]_\lambda$) load ranged from about 22.8 milligram/cubic metre/year to about 46.26 milligram/cubic metre/year whereas normalized chlorophyll, $[Chl]_\lambda$, varied from about 5.63 milligram/cubic metre/year to about 11.11 milligram/cubic metre/year respectively for summer season (Figure 4). The Vollenweider model calculation depicted that the lake showed eutrophic characteristics up to about 3.5-metre depth and mesotrophic for lake depth four metres onward at minimum average phosphorous loading (Table 3) for the same season. Similarly, the average seasonal normalized phosphorous (PO_4-$P[P]_\lambda$) load ranged from about 47.29 milligram/cubic metre/year to about 95.90 milligram/cubic metre/year whereas normalized chlorophyll, $[Chl]_\lambda$, varied from about 11.34 milligram/cubic

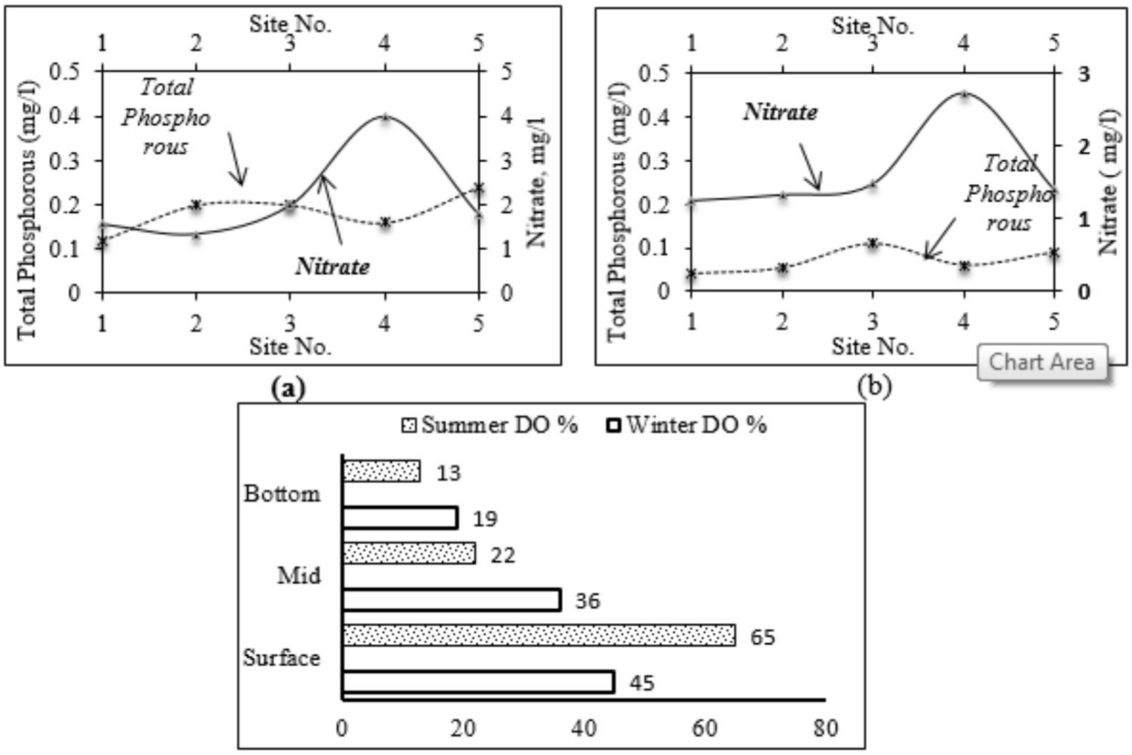
Table 1: Water quality, Nagdaha Lake

Parameters	*Winter*						*Summer*					
	Site 1	*Site 2*	*Site 3*	*Site 4*	*Site 5*	*Average*	*Site 1*	*Site 2*	*Site 3*	*Site 4*	*Site 5*	*Average*
pH	7.7	7.9	7.7	7.8	8.1	7.8	6.7	6.8	6.9	6.9	6.9	6.8
Total Alkalinity as $CaCO_3$ (mg/l)	81.5	84.3	90.3	114.4	132.4	86.8	68.1	72.6	72.6	68.1	81.7	72.6
Nitrate (mg/l)	1.55	1.33	1.99	3.99	1.77	2.13	1.25	1.33	1.48	2.73	1.4	1.64
Total Phosphorus as PO_4 – P (mg/l)	0.12	0.2	0.2	0.16	0.24	0.18	0.04	0.05	0.11	0.06	0.09	0.071

	Winter				*Summer*			
Specific parameters	*Surface*	*Mid*	*Bottom*	*Average*	*Surface*	*Mid*	*Bottom*	*Average*
Dissolved Oxygen (mg/l)	4.4	3.5	1.8	3.23	4.5	1.3	0.8	2.79
Temperature (°C)	15	14	13	14	18	15	14	16

Based on laboratory measurement data 2011 and 2012.

metre/year to about 22.77 milligram/cubic metre/year respectively (Table 2) for winter season. At minimum phosphorous loading condition, the lake showed hypereutrophic characteristics up to about one metre depth and eutrophic for lake depth 1.5 metres onward for this season.



(c)

Figure 3: Comparison of water quality parameters: (a) variation of nitrate and total phosphorus for winter season, (b) variation of nitrate and total phosphorus for summer season, and (c) variation of saturation DO% of winter and summer seasons.

Table 2: Average normalized phosphorous and chlorophyll loading at maximum phosphorous loading

Depths (m)	*Residence time (τw) Year*	*Observed Values (Winter)*			*Observed Values (Summer)*		
		Average PO_4-$P[P]_\lambda$ loading (mg/m³/year)	*Average chlorophyll $[Chl]_\lambda$ (mg/m³/year)*	*Trophic characteristic*	*Average PO_4-$P[P]_\lambda$ loading (mg/m³/year)*	*Average chlorophyll $[Chl]_\lambda$ (mg/m³/year)*	*Trophic characteristic*
0.5	0.11	151.98	34.81	Hypereutrophic	90.57	21.18	Hypereutrophic
1	0.21	132.06	30.42	Hypereutrophic	78.63	18.49	Eutrophic
1.5	0.32	118.06	27.31	Hypereutrophic	70.33	16.61	Eutrophic
2	0.43	107.25	24.91	Hypereutrophic	63.85	15.14	Eutrophic
2.5	0.53	98.49	22.95	Hypereutrophic	58.66	13.96	Eutrophic
3	0.64	91.19	21.32	Hypereutrophic	54.33	12.55	Eutrophic
3.5	0.75	84.99	19.95	Hypereutrophic	50.61	12.11	Eutrophic
4	0.85	79.95	18.72	Eutrophic	47.43	11.38	Eutrophic
4.5	0.96	74.95	17.66	Eutrophic	44.65	10.74	Eutrophic
5	1.064	70.808	16.720	Eutrophic	42.170	10.166	Eutrophic

Based on laboratory measurement data calculation, 2011 and 2012.

Table 3: Average normalized phosphorous and chlorophyll loading at minimum phosphorous loading

Depths (m)	*Residence time (τw) Year*	*Observed Values (Winter)*			*Observed Values (Summer)*		
		Average PO_4-P[P]$_\lambda$ loading (mg/m³/year)	*Average chlorophyll [Chl]$_\lambda$ (mg/m³/year)*	*Trophic characteristic*	*Average PO_4-P[P]$_\lambda$ loading (mg/m³/year)*	*Average chlorophyll [Chl]$_\lambda$ (mg/m³/year)*	*Trophic characteristic*
0.5	0.11	95.91	22.77	Hypereutrophic	46.26	11.11	Eutrophic
1	0.21	83.33	19.55	Hypereutrophic	40.16	9.70	Eutrophic
1.5	0.32	74.50	17.56	Eutrophic	35.92	8.72	Eutrophic
2	0.43	67.67	16.01	Eutrophic	32.61	7.94	Eutrophic
2.5	0.53	62.15	14.75	Eutrophic	29.96	7.32	Eutrophic
3	0.64	57.55	13.70	Eutrophic	27.75	6.80	Eutrophic
3.5	0.75	53.63	12.81	Eutrophic	25.85	6.36	Eutrophic
4	0.85	50.63	12.03	Eutrophic	24.23	5.97	Mesotrophic
4.5	0.96	47.29	11.35	Eutrophic	22.80	5.63	Mesotrophic
5	1.064	44.68	10.75	Eutrophic	21.54	5.33	Mesotrophic

Based on laboratory measurement data calculation, 2011 and 2012.

Discussion

Nagdaha lake has been used as the recreational destination (Dangol, 2011); visitors might haphazardly throw solid wastes and residual food items directly into the water body. The intensive use of chemical fertilizers and pesticides from agricultural lands surrounding the wetland causes the eutrophication which in turn increase algal biomass seriously affecting the water quality especially by creating anaerobic conditions. Besides, the increase in washing and cleaning habits of the local people further contribute the additional effluent directly into the lake water. No specific water utilization point was so far identified. These all concluded that the lake was at the state of high pressure from being contaminated.

The average values for pH, total alkalinity, nitrate and total phosphorous in the lake for winter season were 7.8, 86.76 milligram/litre, 2.13 milligram/litre and 0.18 milligram/litre respectively whereas these were 7.4, 80.33 milligram/litre, 1.9 milligram/litre and 0.13 milligram/litre for summer. The average water temperature in summer was about two degree Celsius higher than winter but the DO value was found deteriorated. Most of the organisms can survive in pH ranges from 5 to 9. The ammonia toxicity rather than declining dissolved oxygen content accounts for low fish population at observed pH level. However, the raising of pH onward symbolized the growth of macrophytes and algae.

The dissolved oxygen in the summer season was observed to be lesser than winter season. It might be due to more sunlight penetrating into the lake water and oxidation of chemical species so present. The observed dissolved oxygen level was at alarming level, which ultimately had been decreasing the spawning activities of fishes resulting in the decline in their population. Some of the local people argued about to extinct of fishes species like *Ctenopharynx godonidella, Cyprinus carpio, Hypophthalmichthys molitrix, Puntius chola Schizothorax richardsonii* etc from lake.

The analytical data entailed that there was gradual decrease in the observed values of water quality parameters from winter to summer gradually. The observed nitrate concentration at Sites 1 and 2 were found to be minimum. It might be due to the reason that it lies a bit far from the agriculture fields and less human interferences. But at Site 4, such influences might be predictable. Besides, wastes from the rising number of hotels and restaurants and aquaculture might be the triggering factors. From these human activities, wastes having nitrates in different form can enter into the lake. However, the observed nitrate in lake water was within the guideline for irrigation water, 5 milligram/litre (GoN/MFSC, 2009). Similarly, critical levels of phosphorus in water were above 0.01 milligram/litre (Rocque, 2002) that likely triggered eutrophication.

It has been found that the concentration of phosphorus at different sample locations is the major contributing factor for the eutrophicaiton. The average total phosphorous level in the lake water was 0.180 milligram/litre in the winter and 0.075 milligram/litre in the summer season for the monitoring period (> limiting value, 0.01 milligram/litre) (Rocque, 2002). At this level phosphorous can trigger for the eutrophication of the lake by reducing the transparency up to one metre (Figure 5) through the raise of productivity in water column (Carr and Neary, 2008). Regarding the limiting

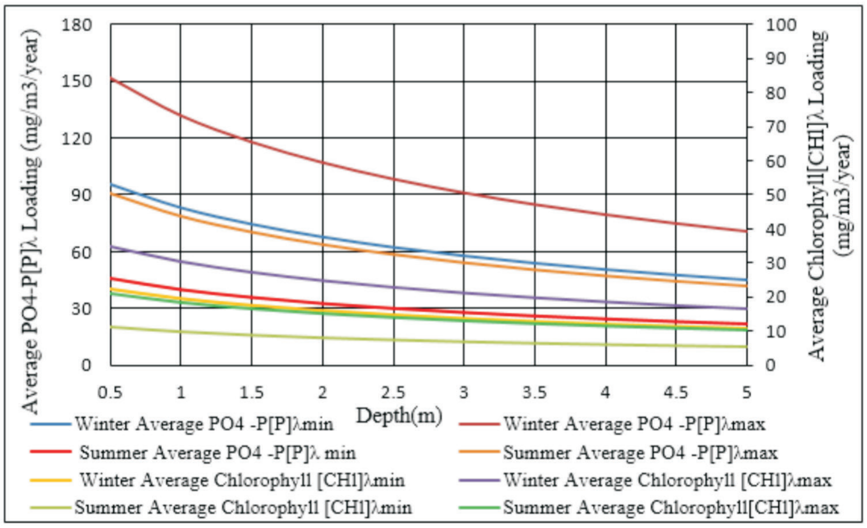
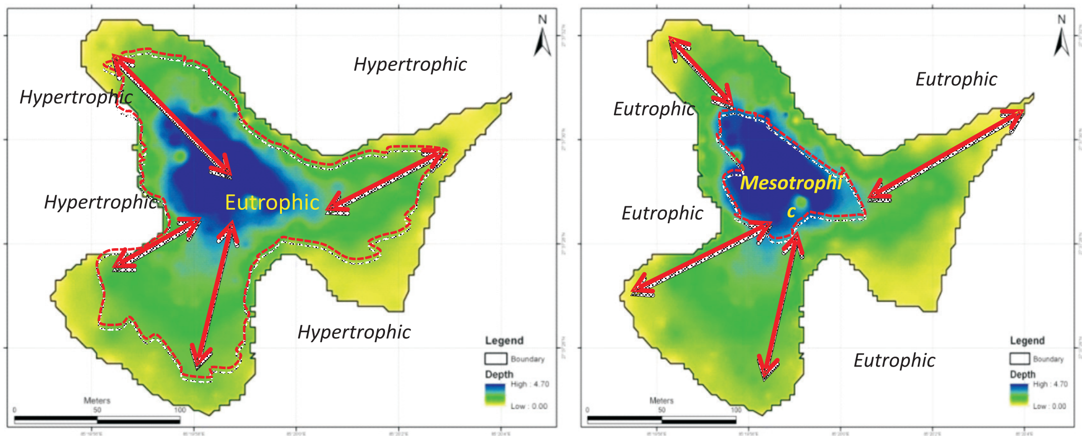


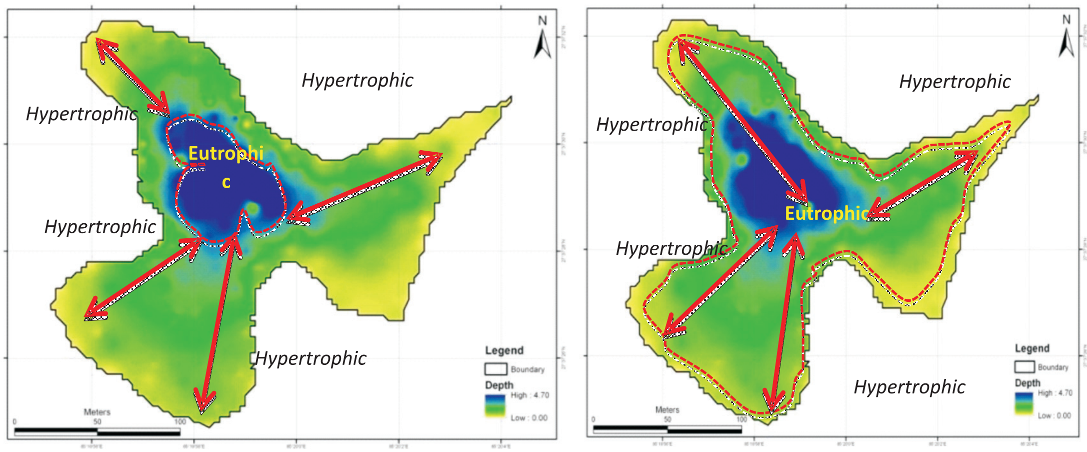
Figure 4: Average phosphorus and chlorophyll for winter and summer season at various depths.

Winter Summer



Trophic characteristics at minimum phosphorous loading

Winter Summer



Trophic characteristics at maximum phosphorous loading

Figure 5: Eutrophication characteristics in winter and summer season.

nutrient status present in the lake, the water should show predominantly eutrophic (high biological productivity on impoundment) and hypereutrophic. The seasonal overturn occurs five times per year.

It was evident that the trophic characteristics decline from winter to summer seasons. In small productive lakes, phosphorus loading from the watershed was shown to decline with decreases in summer precipitation due to reduced nutrients inputs to the lake and longer stratification as indicated in the eutrophication study for small lakes in Ontario (Dillon and Molot, 1997), and the appearance of an open-water algal community dominated by species adapted to low nutrient conditions (Findlay, 2001). The study of Lake Michigan, which suggested that primary production would decline slightly because nutrient inputs to surface waters from the sediments would be reduced by the earlier onset of thermal stratification (Brooks and Zastrow, 2002). These findings suggested that warmer and drier summers, or prolonged or stronger stratification, will lead to lower nutrient levels, thus lower primary production in many lakes (Boyce et al., 1993; Croley, 1994; Peeters et al., 2002). The case was also similar in the study. The change in water quality parameters and trophic characteristics were predictable due to the season overturn of the lake water.

In contrast, Nagdaha is shallow spring lake in which hydraulic and chemical residence time are differed for those lake fed by river. Generally, the residence time depends on inflow, outflow, assuming steady state conditions and how large the system is. Both the residence time for the one corner of lake may be different to rest of the site depending on these conditions. For example, the residence time may be different in Site 5 compared to other sites because it was selected near outlet of the lake. In Vollenweider model, the residence time for particular aquatic body is calculated based on the total area multiplied by specified depth and divided by total water volume. Mathematically, this means that the residence time of water body or chemicals in particular site is determined to be similar to corresponding depth of other site. As a result, the various trophic levels were classified based on residence time and total amount of phosphorus measured. Also, due to the action of wind, stratification, temperature and rapid evaporation, minimum residence time was calculated at surface followed by slight increase towards bottom region.

Based on calculated value of residence time, it was reported that first few metres were hypereutrophic and rest were eutrophic (Figure 5). In addition, the OECD eutrophication modelling approach appropriately considers the impact of a water body's depth through the mean depth normalizing factor (Vollenweider, 1976). In this study, the concept of OECD model was applied and various levels were calculated based on the depth of water body. As mentioned in result, the eutrophy level was found increasing with decrease in hydraulic residence time analogues to phosphorus residence time which was same as the result obtained by Rast and Lee (1978) based on U.S. OECD data.

Eutrophication of a lake system is gradual progression from one life stage to another based on the changes in the degree of nutrient input or productivity (Sharma, 2010). In Nepal, there are a number of policy, act documented for the protection of wetlands. Nepal undersigned Ramsar Convention on 17^{th} April 1988 which was accounted to prevent the loss of wetlands. In 1992, Water Resources Act was formulated to minimize environmental damage to wetlands especially lakes and rivers through environmental impact assessment. In Nepal Biodiversity Strategy 2002, Ministry of Forest and Soil Conservation included number of lakes for legal protection. Later, National Wetlands Policy 2003 has been regarded as effective policy for the conservation and management of wetland resources wisely and in a sustainable way with local people's participation. Besides the political instability, various NGO's, private organizations, local manpower and foreign donors have been actively involved in restoring the wetlands.

It has been found that the eutrophication process is a complex phenomenon affected by a number of physical, chemical, biological and social factors. Based on OECD eutrophication model, phosphorus is the parameter that limits the maximum planktonic algal biomass and affects the water quality. It is therefore logical to focus on control of phosphorus for the management of water body by finding the potential sources. Agriculture is the major source for livelihood of people around the lake who often change the land use pattern with increased phosphorus loading which produced greater amounts of phytoplankton; this finally makes the water uninhabitable for them. Furthermore, water quality characteristics are being judged based on desired beneficial uses of specific water body. For example, eutrophication control measures may be appropriate for water body that users could enjoy for aesthetic pleasing and warm water sports fishery.

Nagdaha lake is a recreational destination as it is famous for aquatic plants, water birds, snakes, boating and fishing as income source for committee involved. Rast et al. (1983) included the general relationship, the greater the phosphorus load, the greater the fish yield. For some extent, eutrophication control might be a matter of trade-off between aesthetics and fishability. It has been well known that millions of dollars have been spent around the world for lake restoration for water quality management over the past 10-20 years. As a part of lake restoration, Nagdaha committee has been initiating to clean the lake and bring it back to its original state by identifying the encroached area. The local villagers, members of local NGO's, women's association and youth club had drafted a plan to clean the vegetation and conducted environmental awareness training programme and regulated support from IUCN Nepal who participated in the endeavour through its NGO, environmental management programme supported by USAID.

Conclusion

Considering winter season, the calculated average normalized phosphorous and chlorophyll concentration entailed that the lake was hypereutrophic and eutrophic up to first 3.5 metres and onward depths respectively at maximum phosphorous while it was hypereutrophic and eutrophic up to one metre and onward depth respectively at minimum phosphorus loading. In summer season, the concentration revealed that the lake was hypereutrophic and eutrophic up to first 0.5 metre and onward depth respectively at minimum phosphorus loading while it was eutrophic and mesotrophic up to 3.5 metres and onward depth respectively at minimum phosphorus loading. So, the trophic characteristic of the lake was ranging from mesotrophic, eutrophic to hypereutrophic for different phosphorous concentrations. The study entailed that there was seasonal shifting of trophic characteristics. The water quality characteristic was found deteriorating in which alkalinity level was found good for the natural water buffering capacity but some sensitive species might be affected. But the dissolved oxygen content was found at severe level (below guideline) for surface, mid and bottom region.

It has been identified that human encroachment, agricultural runoff, siltation, pollution, eutrophication and other commercial activities are keeping threats to size and water quality of Nagdaha lake. The recent aerial photograph basis, litreature and present study, the area of the lake has been decreased by 500 square metres. The committee has been initiating to clean the lake as a part of restoration and bring it back to its original state by identifying the encroached area. But, they are not aware about eutrophication control measures and least attentive for odour control as well as nearby agro land runoff control. As the phosphorus is the limiting factor for eutrophication, it should be controlled by finding its potential sources. At the same time, while controlling the phosphorus, it is more important to consider people's aesthetic enjoyment and fishability. It is encouraged that the regular and effective monitoring activities are vital to maintain natural water quality characteristics within standards, act and policy for the sustainable management of lake. Multidisciplinary approach is highly desirable to understand and control eutrophication in which government, policy makers and public should be involved.

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