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Implications on Lake Phewa and Kulekhani Reservoir of Chemical Fertiliser Application by Farmers

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Abstract: This study analysed factors influencing the decision to use chemical fertilisers by farmers at the household level, and it included a related assessment of nutrients in nearby water bodies. One focus group discussion was held at each site, and then a total of 198 and 58 households in Lake Phewa and Kulekhani Reservoir, respectively, were surveyed. The results reveal that 90% and 55% of households applied chemical fertilisers in Lake Phewa and Kulekhani Reservoir, respectively. A logistic regression model indicated that the two factors having a significant positive influence on the decision to use chemical fertilisers were higher vegetable yield and the amount of urea available to farmers Water sampling indicated that phosphorous concentrations were relatively high in both these water bodies compared to previous studies in other nearby lakes.

Key words: DAP, fertiliser, Kulekhani Reservoir, Nepal, nutrient loading, Phewa Lake, urea.

Introduction

Agriculture, the main source of livelihood for the Nepalese population, is characterised in Nepal by a high percentage of subsistence farming with inadequate market access and high food production cost (Hussain et al., 2016). More than half (53%) of the farmers in Nepal are classified as landless/near landless (<0.05 ha), 27% have very small areas (0.5-1 ha) they subsist on, and 20% represent small commercial farmers (1-5 ha). The overall average farm size per capita has decreased recently to 0.6 ha (GoN, 2016). Farming primarily depends on formerly predictable seasonal rainfall, but this is becoming more erratic due to high climate variability with more floods and draughts at the wrong time.

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The Government of Nepal defines agricultural commercialisation as "the transformation from subsistence production to production for sale of surplus products" (GoN, 2016). Most studies consider agricultural commercialisation in terms of the volume of marketable commodities which means that a farming family is selling a significant surplus of its agricultural production (Jaleta et al., 2009). However, the capacity of farmers to become productive commercial farmers is limited (BRACED, 2019).

One of the key strategies of the Government of Nepal (GoN) has been to improve agricultural production over the last three decades and it has focused on high-value commodities in the hill and mountains regions, and foodgrain production in the Terai region. These priorities include plans for wellcontrolled year-round irrigation, increased fertiliser use, improved agricultural technology, increased road networks and rural electrification, and agribusiness development (APP, 1995). Furthermore, the GoN initiated the Agriculture Modernization Project to enhance agricultural productivity. The GoN has recently launched the Agricultural Development Strategy (2015–35), with support from the Agricultural Development Bank, and the 2018 "Roadmap to Prosperity" (NPC, 2020). The intent of all of these plans is for agricultural sector growth through governance, productivity, profitable commercialisation and competitiveness in agricultural trade. The approach is to promote social and geographic inclusiveness, sustainability, development of the private and cooperative sectors, market infrastructure connectivity, and information and power infrastructure (GoN, 2016). The agriculture development strategy has flagship programs such as food and nutrition security, value chain development, innovation and agro-entrepreneurship.

Since traditional subsistence farming alone has become an insufficient livelihood source, many Nepalese farmers are commercialising their use of farmlands (GC & Hall, 2020; Kanini, 2020; Paudel et al., 2014; Raut et al., 2012). There is a growing tendency to increase chemical fertiliser application for cash crops with high market value such as tomatoes and potatoes. This implies increasing the area under the three-cropping system (Raut et al., 2011). Crops only use 30-50% of the chemical fertiliser applied and only 1% of the pesticide used, the remainder is discharged into the environment (Mózner et al., 2012; Norse, 2005). Chemical and biological degradation of soil is occurring due to the overuse of chemical fertilizers (Chalise et al., 2019). Average soil loss in the upland sloping terraces was estimated to be 28 t ha^{-1} $year^{-1}$ whereas soil loss from lowland levelled terraces is 0.7 t ha^{-1} $year^{-1}$ (Bajracharya & Sherchan, 2009). The higher soil loss from upland-sloping terraces may be due to the frequent tilling of steep slopes for intensifying crop production. Runoff of chemical fertilisers residues and pesticides from erosion enters water bodies leading to eutrophication and nitrate in groundwater (Liu et al., 2017; Rai, 2000).

In recent years, chemical fertiliser application by hill and mountain farmers has increased (Guo et al., 2022; Thapa et al., 2019). Numerous studies have focussed on soil properties, and eutrophication of freshwater bodies in isolation (Gurung et al., 2021; Raut et al., 2012). Therefore, studying the driving mechanisms of the use of chemical fertiliser can contribute to understanding how to achieve sustainable agricultural development. Only a few studies have examined the determinants of fertiliser application (Raut et al., 2011). This study first analysed factors affecting the decisions to apply chemical fertilisers by farmers. Second, it examined the amount of nitrogen and phosphorous addition in water bodies. A correlation is established between the motivating factors of using chemical fertilisers in soil and nutrient loading in nearby water bodies.

Methodology

Study Area

The study was conducted in two sites in Nepal; Lake Phewa and Kulekhani Reservoir (Figure 1).

Lake Phewa is a semi-natural freshwater lake lying at an elevation of 796 masl in Pokhara Valley. The climate is humid subtropical to cool temperate monsoon. The mean average temperature varies between 12°C in winter and 30°C in summer. The lake occupies an area of 5.23 km^2 (Lamichhane, 1996). The main inlets to the lake are Harpan Khola in the west and seasonal inlets on the northern side. Land use patterns in the lake catchment basin include agriculture and dense urban areas in the north; forest in the south; a silt trap zone on the western side; and an outlet on the eastern side.

Kulekhani Reservoir is located in Makwanpur district, central Nepal (Figure 1). The climate varies from subtropical to temperate. The average temperature ranges from 15°C to 20°C (Ghimire, 2004). The average annual precipitation is 1500 mm, 80 % of which occurs between June to September. The major streams that enter the reservoir are Tasar, Bisingkhel and Chitlang Khola. The watershed consisted of 42% agricultural land; 44% forest land; 9% shrubland; 2% grazing land; and the reservoir, rock field, landslides and residential area cover 3% of the total watershed area.

Data Collection

Focus Group Discussion and Questionnaire Survey

One focus group discussion was conducted in each study site with 15 to 20 farmers including both males and females. The group discussion mainly focused on the types of crops grown, types of fertilizer used, yield, and access to markets. Household surveys were conducted in the wards adjoining Lake Phewa and Kulekhani Reservoir following a systematic sampling method. During the group discussions, farmers were asked to prepare a list of other farmers in the near vicinity of both study sites who were involved in commercial farming ("users of chemical fertilisers") and traditional farming ("non-users of chemical fertilisers"). A total of 198 farming households were surveyed in the Lake Phewa watershed and 58 households were surveyed in the Kulekhani watershed. The surveys were conducted among household heads using a semi-structured questionnaire. Information was collected on socio-economy, landholdings, type and amount of fertiliser applied, the productivity of crops, and distance to the farmland from the homestead. The survey was done from November to December 2018.

Water Sample Collection

Water sampling was conducted from October 2017 to 2018 representing four seasons, namely, Post-monsoon, Winter, Pre-monsoon and Monsoon. Water samples were collected from 10 sites (six from inlets and four from the main lake) in Phewa Lake and nine sites (five from inlets and four from the reservoir) in Kulekhani Reservoir (Figure 1). The sampling sites were selected to ensure representation of the entire water bodies including inlets, outlets, and middle of the lake based on the accessibility. Water samples of 1000 ml were collected in high-density polyethylene bottles from each site. The sampling bottles were rinsed with the lake/reservoir water in each sampling site before sample collection and after samples were collected, they were immediately stored in an icebox until they were transported to the laboratory for further analysis.

The anions NO_3^- was analysed by Dionex ISC-2500 ion chromatograph using an IonPac AS11-HC analytical column, IonPac AG11-HC guard column, 20 mmol/L potassium hydroxide (KOH) eluent, and ASRS 300 continuous self-regeneration anion suppressor. Total phosphate was estimated following standard procedures with a spectrophotometer (APHA, 2012).

Selection of Dependent and Explanatory Variables

Agriculture in much of Nepal is characterised by a triple cropping system that includes shorter growing season varieties and no fallow period (Dahal et al., 2007). In irrigated land, the national average number of crops increased from 1.6 (in 1987) to 2.7 (in the 1990s) (Schreier et al., 1994). Farmers in both study areas are shifting from traditional ways of farming to commercial

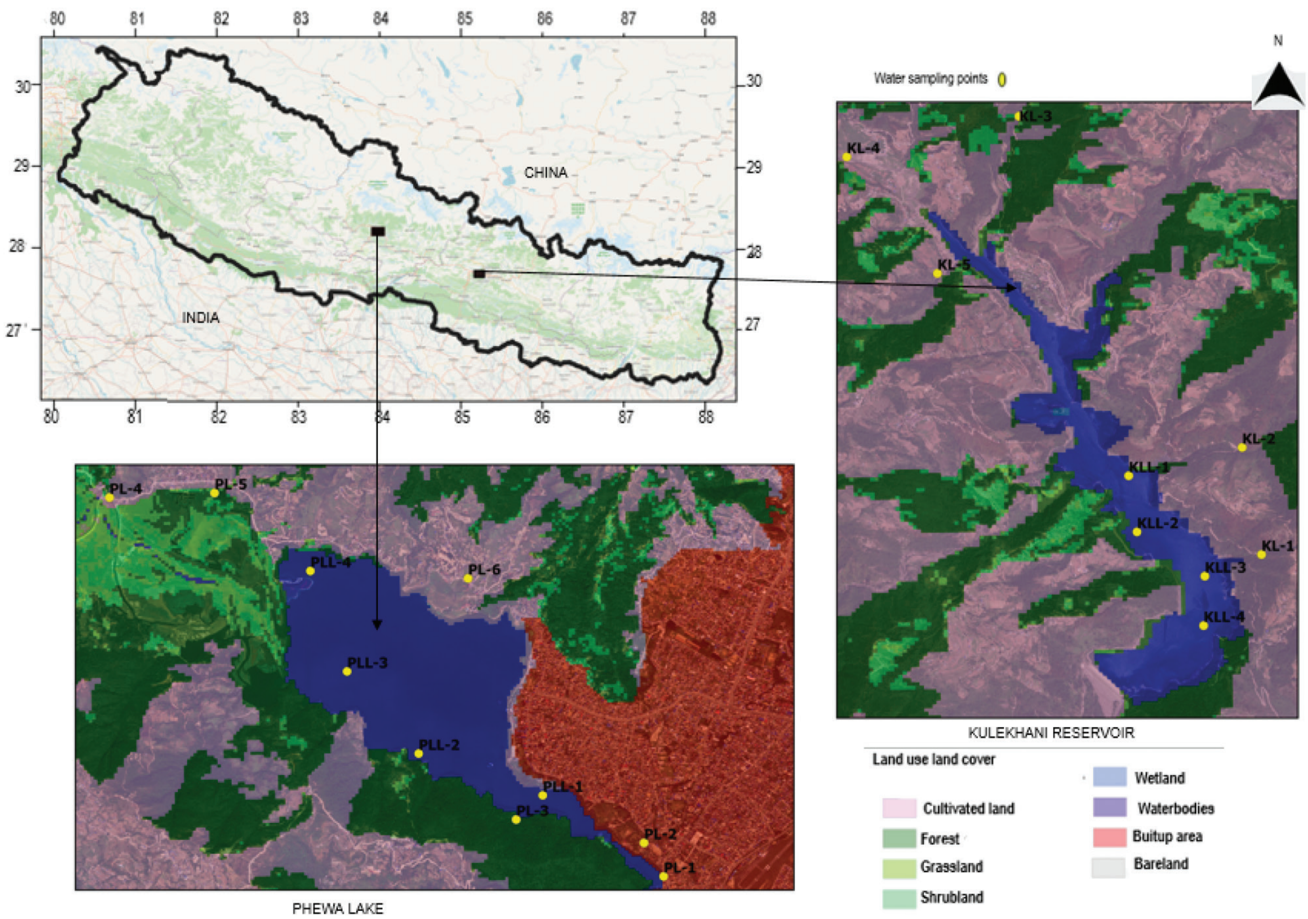

Figure 1: Location map of study area showing water sampling points.

farming. In traditional farming, farmers grow mostly cereal crops. The number of crops, mainly vegetables, adopted by the farmers was used as an indicator of users of chemical fertilisers and therefore was used as the dependent variable for making decisions to apply chemical fertilisers using a logistic regression model. A value of 1 was assigned to respondents who used chemical fertilisers (the "users") and 0 to respondents who do not use chemical fertilisers (the "non-users"). Making decisions on whether or not to apply chemical fertilisers in their farmlands is influenced by various independent variables listed in Table 1.

In the beginning, 13 independent variables were examined for a co-linearity effect of the independent variables in the correlation analysis. The independent variables with a high degree of correlation with each other and a low degree of correlation with the dependent variables were excluded from the model. A total of 10 independent variables were used in the model (Table 1). "Gender" is a dummy variable (female=1; 0=male). Households headed by a male are expected to have greater chances of using chemical fertilisers than those headed by a female. The Nepalese society is divided into three broad castes based on the profession of the people, and values for the dummy variable "caste" were: 3= the upper castes (Brahmin/Chhetri), 2= the middle castes (Newar & Janajati), and 1= to the lower castes. "Farm distance", is a continuous variable and is the distance to farm lands from the homestead, measured in minutes. It has been found that the farmlands that are near homesteads have greater possibilities of supervision by the farmers (Xuefeng et al., 2008), and thus the adoption of vegetables for commercial purposes is more likely. It is hypothesised that the higher the "vegetable yield", the greater the possibility of their cultivation and an increase in the use of chemical fertilisers. Farmers owning larger landholdings may be able to invest in new technologies and thus achieve better returns. It is expected that farmers owning larger landholdings are willing to cultivate more areas for vegetables which will lead to increased use of chemical fertilisers. Irrigation is a major factor for commercial cultivation, thus increased irrigated land will enhance vegetable cultivation and this is accompanied by increases in the use of chemical fertilisers. It is also expected that the availability of chemical fertilisers and the absence of farmyard manure also motivate farmers to use chemical fertilisers in their farmlands.

Model Specification Binary Logistic Regression Model: Use of Chemical Fertilisers

A binary logistic model was used to understand the relationships between dependent and independent variables. The dependent variable chosen was the willingness/decision to apply chemical fertiliser at the household level. Since the decision to apply or not to apply chemical fertilizer is a dichotomous variable, with the options of users and nonusers, the binary logistic regression model was applied as the most appropriate tool to investigate how each independent variable affects the probability of the occurrence of events. The equation is specified as follows:

$$\text{Ln}\ [P_i / (1\text{-}P_i)] = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots\ldots\ldots + \beta_k X_{ki}$$

where the subscript i means the i^{th} observation in the sample. P is the probability of willingness to apply chemical fertilisers and (1-P) is the probability of non-willingness to apply chemical fertilisers. β_0 is the intercept term and $\beta_1, \beta_2, \ldots\ldots\ldots, \beta_k$ are the coefficients of the independent variables $X_1, X_2, \ldots\ldots\ldots, X_k$.

Results and Discussion

Characteristics of Users and Non-users of Chemical Fertiliser

Of the 198 respondents (from Lake Phewa) and 58 respondents (from Kulekhani Reservoir), 90% and 55%, respectively, were identified as users of chemical fertilisers. There were no significant differences in caste and gender between users and non-users of chemical fertilisers (Table 1). The continuous variables; total landholdings, irrigated land, the yield of vegetables, amount of farmyard manure, and amount of phosphorus fertilisers were all significantly higher among adopters in both the study areas. However, farm distance from the homestead was significantly higher among non-users, and urea applications were significantly higher among users of chemical fertilisers in Kulekhani Reservoir. The Chi-square tests show that access to credit is significantly higher among adopter farmers (Table 1).

Determinant Factors on Decision to Apply Chemical Fertilisers

The influence of variables on the willingness of farmers to apply chemical fertiliser is shown in Table 2 and Table 3. The log-likelihood is 42.457 and 14.150; and overall, the model correctly predicted 94.8 % and 91.7 % of the variation in the decision to apply chemical

Table 1: Description and summary statistics (mean and percentage) of the variables used in the binary logistic model (n=198 in Lake Phewa and n=58 in Kulekhani Reservoir)

Variables	*Description*	*Lake Phewa*			*Kulekhani Reservoir*		
		Users of chemical fertiliser n = 179	*Non-users of chemical fertiliser n = 19*	*Significance*	*Users of chemical fertiliser n = 32*	*Non-users of chemical fertiliser n = 26*	*Significance*
Users	Dependent variable: Users of chemical fertilisers						
Gender[a]	Sex of the respondents (%)			0.250			0.071
	Male (%)	77	84		88	69	
	Female (%)	23	16		12	31	
Caste[a]	Caste of the respondents (%)			0.341			0.097
	Bhramin/chhetri	82	67		4	7	
	Janajati	17	33		90	86	
	Others	1	0		6	7	
Distance[b]	Distance of farmland from homestead (minutes)	43	58	0.072	26	51	0.047*
Total landholding size[b]	Total landholdings (ha/hh)	0.71	0.55	0.030*	0.66	0.39	0.023*
Total irrigated land[b]	Irrigated land (ha/hh)	0.76	0.45	0.041*	0.68	0.36	0.044*
Vegetable yield	Productivity of vegetables (kg/ha)	717	312	0.026*	948	292	0.001**
Farm yard manure	Farm Yard Manure (FYM) application (kg/ha)	6362	11417	0.002**	5124	8549	0.032*
Potassium fertiliser	Potash application (kg/ha)	9.6	0	-	8.1	0	
Diammonium Phosphate fertiliser (DAP)	DAP application (kg/ha)	12.7	3	0.002**	10.3	4	0.020*
Urea fertilizer	Urea application (kg/ha)	20.7	0	-	24.5	5	0.001**

[a] Dummy variable; [b] Continuous variable; * $p<0.05$; ** $p<0.01$

fertilizers among the respondents in Lake Phewa and Kulekhani Reservoir, respectively.

The model output revealed that six variables positively influenced the decision to use chemical fertilizer in Lake Phewa. However, only the increase in vegetable productivity and availability/application of urea fertiliser were significant (Table 2). Four variables: gender, caste, location of farmland from the homestead, and total landholdings appeared to negatively influence the decision to apply chemical fertilizers, but none were significant. For Kulekhani Reservoir, the model revealed that seven variables positively influenced the decision to use chemical fertilizers. However, only three variables, namely: vegetable productivity, availability/application of urea fertilizer and irrigated land were significant. Three variables: gender, total landholdings, and amount of farmyard manure application appeared to negatively influence the decision to apply chemical fertilisers, but none were significant (Table 3).

This shows that farmers in study areas who do vegetable farming were satisfied with the productivity, and thus had an inclination to shift from traditional

Table 2: Maximum likelihood estimates of the decision to use chemical fertilizer model in Lake Phewa

Variables	*Coefficient*	*S.E.*	*Sig.*	*Odds ratio*
Gender	-0.477	1.213	0.694	0.621
Caste	-0.288	0.355	0.417	0.750
Location of farmland from homestead (in minutes)	-1.334	1.500	0.374	0.263
Total landholdings (ha)	-0.346	1.424	0.808	0.707
Irrigated land (ha)	0.261	1.726	0.880	1.298
Productivity (kg/ha)	0.002	0.001	0.012*	0.998
Farm Yard Manure (FYM) application (kg/ha)	0.001	0.012	0.367	1.000
Potash application (kg/ha)	20.494	45.427	0.989	1.873
DAP application (kg/ha)	0.005	0.055	0.929	1.005
Urea application (kg/ha)	0.425	0.150	0.005*	1.530

Hosmer and Lemeshow Test: Chi-square = 4.201, d.f. = 7, Sig. = 0.001, -2 Log likelihood = 42.457, Cox & Snell r^2 = 0.327; Nagelkerke r^2 = 0.715; overall percentage of right prediction = 94.8%; sample size = 198 households. * $p<0.05$.

Table 3: Maximum likelihood estimates of the decision to use chemical fertilizer model in Kulekhani Reservoir

Variables	*Coefficient*	*S.E.*	*Sig.*	*Odds ratio*
Gender	-0.993	2.218	0.654	0.370
Caste	4.035	2.371	0.089	56.562
Location of farmland from homestead (in minutes)	2.836	1.693	0.094	17.050
Total landholdings (ha)	-29.652	17.317	0.087	0.001
Irrigated land (ha)	35.356	19.114	0.034*	2.263
Productivity (kg/ha)	0.278	0.133	0.037*	1.320
Farm Yard Manure (FYM) application (kg/ha)	-0.051	0.050	0.304	0.950
Potash application (kg/ha)	5.391	2.879	0.061	21.528
DAP application (kg/ha)	28.104	14.751	0.057	1.605
Urea application (kg/ha)	8.234	11.276	0.048*	0.003

Hosmer and Lemeshow Test: Chi-square= 2.310, d.f. = 7, Sig. = 0.941, -2 Log likelihood = 14.150, Cox & Snell r^2 = 0.517; Nagelkerke r^2 = 0.832; overall percentage of right prediction =91.7 %; sample size = 58 households. * $p<0.05$.

agricultural farming to commercial vegetable farming. Because farmers are affected by market factors (e.g., prices), they are more inclined to plant orchard and vegetable crops which have higher yields when chemical fertilizers are used (Li et al., 2020; Zinda and Kapoor, 2019). Likewise, in both sites, the availability of urea fertiliser to farmers motivated them to use fertiliser in commercial vegetable production. This also proved that urea is the main fertilizer that farmers prefer to apply on their farms. Moreover, irrigation facilities also motivated farmers near Kulekhani Reservoir to grow more vegetables and use chemical fertilisers. The magnitude of the regression coefficient shows that positively influencing factors have more influencing power on the decision to use chemical fertilisers than negatively influencing factors. Farmers during the group discussion mentioned that vegetable farming expanded near Lake Phewa due to an increasing number of hotels, whereas vegetable farming began to increase almost 20 years ago in the Kulekhani watershed area due to high market value in Kathmandu.

While large household farmers often increased the amounts of chemical fertiliser applied in order to pursue higher yields, some farmers are switching to organic fertiliser and biological pesticides to reduce harmful impacts on the environment (Wang et al., 2018; Zheng et al., 2020). Currently, local retail fertiliser stores and cooperatives provide fertilisers to farmers urea being the major source of nitrogen fertiliser after diammonium phosphate (DAP) (Raut et al., 2011;

Westrap et al., 2004). In both the study areas, farmers reported that they get urea and DAP fertiliser from the nearby shops most of the time, and only occasionally did they have to buy from distant shops. Therefore, the local availability of chemical fertilisers enhanced their use. However, the level of farmers' awareness of agro-chemicals also inspires them to avoid environmental problems caused by excessive use of chemical fertilisers and pesticides while pursuing high harvests (Qin et al., 2020; Zhu & Wang, 2021). A similar relationship was found in Malawi where a national fertilizer policy led to a substantial increase in fertiliser application, which in turn has led to a speedy rise in food production (Dorward & Chirwa, 2011).

Nitrate and Total Phosphorus in Both Water Bodies

Nitrate was significantly lower in summer compared to the winter and autumn seasons in Phewa Lake ($p<$ 0.001). However, it did not show significant seasonal variation in the Kulekhani Reservoir. The average concentration of nitrate in Phewa Lake (0.03±0.05 mg/L) and Kulekhani Reservoir (0.07±0.11 mg/L) were relatively low, based on previous studies, compared to other nearby lakes (Figure 2).

The average concentration of phosphate in Phewa Lake (0.48±0.71 mg/L) and Kulekhani Reservoir (0.51± 0.77 mg/L) were relatively higher in comparison with previous studies in other nearby lakes, and it showed a significant seasonal variation in both water bodies, being higher in winter in Kulekhani ($p<0.05$) (Figure 3).

The total phosphorus concentrations in both the water bodies were lower during the pre-monsoon and monsoon seasons but increased during the autumn indicating an increase in the allochthonous inputs during precipitation. The nutrient loading in Lake Phewa has been attributed to agriculture, landslides, untreated sewage and rapid urbanisation in the surrounding areas which have caused the eutrophication of the lake (Rai, 2000). Increased phosphorus loading from the watershed during the monsoon contributes to algal growth (Jung et al., 2016; Kafle et al., 2023). The catchment of the Kulekhani reservoir consists of intensive commercialized vegetable production which receives large phosphate concentrations due to run offs from these fields where chemical fertilisers and farmyard manures are being applied (Adhikary et al., 2020). The runoff during the monsoon is almost three times higher than in other seasons (Shrestha et al., 2014) bringing in increased concentration of nutrients. This may explain the hypereutrophic nature of Lake Phewa and Kulekhani Reservoir during the monsoon.

Increasing phosphate concentrations in freshwater bodies during monsoon are attributed to increased sedimentation resulting from catchment erosion and agricultural runoff (Jain et al., 2000). Similar findings have been observed in lakes and reservoirs in Brazil, Korea and South East Asia which showed higher nutrient concentrations during the rainy season (Jung et al., 2016; Mamun & An, 2017). For most lakes, phosphorus is often the limiting component and its control is of key importance in dropping the accelerated eutrophication of a water body. However, the impacts of the intensity of agriculture on water chemistry increase from consequent eutrophication and food web modification (Moss, 2008; Withers et al., 2014) to biocide leaching (Kristensen & Kostka, 2005), suspended loads from

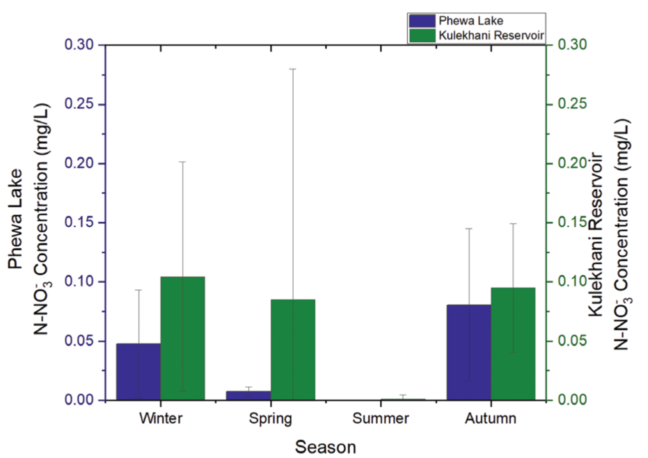

Figure 2: Concentration of $N\text{-}NO_3^-$ of Lake Phewa and Kulekhani Reservoir.

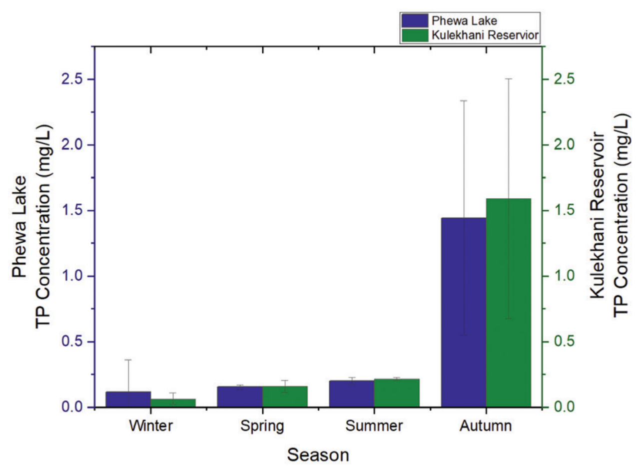

Figure 3: Concentration of total phosphorous (TP) of Lake Phewa and Kulekhani Reservoir.

soil erosion (Brodie & Mitchell, 2005), and alteration of the hydrological cycles (Williams & Aladin, 1991).

Conclusions

The factors that influence farmers' decisions to use chemical fertilisers show that improved yield from vegetables, and the amount of urea fertiliser available play influential roles. The irrigated land has influenced farmers' decision to use chemical fertiliser in more intensively cultivated land in Kulekhani Reservoir. The decision to use chemical fertiliser is a gradual process and is influenced by thriving economy and institutions making fertiliser more available. The average concentration of nitrate in Phewa Lake and Kulekhani Reservoir was relatively low, while the concentration of phosphate in both water bodies was relatively high. As indicated above, the nutrient loading and eutrophication in both water bodies are likely influenced mainly by agricultural runoff. The emergence of recent market opportunities has increased the application of chemical fertilisers more than any other factor with negative consequences to water quality. Thus, a sustainable approach to farming systems is needed for the optimal use of fertilisers and to reduce nutrient loading in freshwater bodies.

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