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Land use and land cover changes in the catchments impact the ecosystem in Phewa, Begnas, and Rupa lakes, Nepal

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ABSTRACT

Lakes are the environmental and socioeconomic assets of Nepal. In the past few decades, land use and land cover (LULC) change and sediment and nutrients loading into the lakes have severely altered the lake ecosystems. Using Landsat satellite images and data from published literatures, this study analyzes the spatiotemporal variations of LULC change and its impact on the environment of Phewa, Begnas and Rupa lakes during 1975–2018. The results showed that from 1975 to 2018, the forest cover and agriculture land in catchments of all three lakes have decreased, while the built-up area has increased. LULC changes in the catchment have bought the significant impact on the lake environment in terms of sedimentation rate, physiochemical parameters and biological environment. From 1975 to 2000, the forest cover in lakes catchment has decreased, whereas the agriculture land has increased. At the same time, sediment and agriculture based nutrient loading into lakes has increased as indicated by changes in the sedimentation rate and the alteration of physiochemical properties of the lakes. From 2000 to 2018, forest and built-up area has increased while the agriculture land has decreased in lakes catchment. From 2000 to 2018, sedimentation rate of lakes has decreased compared to before 2000. The decreased sedimentation rate was attributed to the increase in the forest cover in the lakes catchment. Increased nutrients loading into the lake during 2000 to 2018 have resulted in serious eutrophication problem in lakes. Overall, this study suggests that the LULC change in the catchment has a significant impact on the lake environment.

Keywords: Land use and land cover; Lake catchment; Lake ecosystem; Eutrophication

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INTRODUCTION

Land use and land cover (LULC) change in the catchment of lakes has a significant impact on aquatic ecosystems by altering the nutrients input, sediment loading and hydrological flow regimes (Jamu et al., 2003; Malthus and Mitchell, 1988; Soranno et al., 1996). These changes have affected several lakes around the world (Jamu et al., 2003; Li et al., 2009; Poraj-Górska et al., 2017). Trophic status and aquatic production of lakes have increased (Haas et al., 2019). Hydro-chemical parameters of the lake water have altered (Martin et al., 2011). Thus, the improved understanding of how LULC change impacts the lake ecosystem is crucial for sustainable management and long-term protection of the aquatic ecosystem.

Pokhara, one of the ancient cities, located at the foothills of >8000 m peaks of the Annapurna Massif in central Nepal, is located about 200 km west from the capital city of Kathmandu. Pokhara valley has a population of about 261 thousand (CBS, 2012). Every year more than one million national and international travelers visit Pokhara (Paudyal et al., 2018). In 2016, nine lakes of Pokhara valley were enlisted as Ramsar sites of Nepal. These lakes provide the supporting, provisioning, regulating and cultural services to local inhabitants as well as to the thousands of national and international visitors to Pokhara (Paudyal et al., 2019). These lakes support high biodiversity, including suitable habitat for many flora and fauna, bird and fish species (Kafle et al., 2008). Also, these lakes play a vital role in determining economic activities such as tourism in Pokhara. However, LULC of Pokhara valley has changed drastically in the past few decades. The urban/built-up area in the Pokhara valley experienced the most significant transformation from 1988 to 2000, with remarkable changes occurred after 2000 (Rimal et al. (2018). The study also revealed a decrease in the agricultural land and an increase in forests (Rimal et al., 2018). At the same time, the lake's ecosystem has significantly changed such as an increase in mercury concentration, trace elements (Sharma et al., 2015), and sedimentation rates (Ross and Gilbert, 1999), while a decrease in the lake water quality (Rupakheti et al., 2017), and volume (Watson et al., 2019). The recent inventory of lakes and water bodies in Nepal by the Department of Forestry (DoF) in 2017 found that 95% of lakes have undergone serious transformations (DoF, 2017). Adhikari et al. (2018) suggest that the recent LULC cover change in the catchment has threatened the Phewa lake. Thus, it is crucial to have an improved understanding of the relationship between LULC change and aquatic ecosystem. Previous researches on Phewa, Begnas, and Rupa lakes have paid more attention to the annual and seasonal limnological condition. There is a lack of studies and historical data on the complete limnological condition and how the LULC, recent climate change and human activities affect the lake ecosystems are poorly understood.

This study reviews the limnological condition, presents the time series analysis of LULC change in catchments of Phewa, Begnas and Rupa lakes. The main aim of the study is to examine how the LULC change and climatic variability affect lake ecosystems in the Pokhara valley. The study provides an overview of Phewa, Begnas and Rupa lake, which may be helpful for the development of environmental management plans, protocols and local level governance.

STUDY AREA

Phewa lake (Fig.1) is the second largest lake in Nepal and the largest lake of Pokhara valley located at an altitude of 742 m. The lake has the surface area, maximum depth, and average depth of 5 km^2, 24 m and 7.5 m, respectively (Rai, 2000b). The eastern shore of the lake is surrounded by Pokhara valley. In 1933, the lake was dammed for irrigation and hydropower generation and the construction detail is described in Ross and Gilbert (1999). Begnas lake (Fig.1), the second largest lake of Pokhara valley, lies at an altitude of 650 m. The lake has 3.28 km^2 surface area, and the maximum and average depth of 20 m, and 6.6 m, respectively (Rai, 2000a). The lake was dammed in 1988 for irrigation purpose. Rupa lake (Fig. 1) is the third-largest lake of Pokhara valley. The lake lies at an altitude of 600 m and has 1.3 km^2 surface area and has a maximum and average depth of 6 m, and 3 m, respectively (Rai, 2000b). The major part of the lake is surrounded by the forest and agricultural fields. The sedimentation rate in Rupa lake is three times higher than that of the Begnas lake (Acharya et.al., 2020). The Phewa, Begnas and Rupa lakes are the natural freshwater lake fed by rainwater and small rivers.

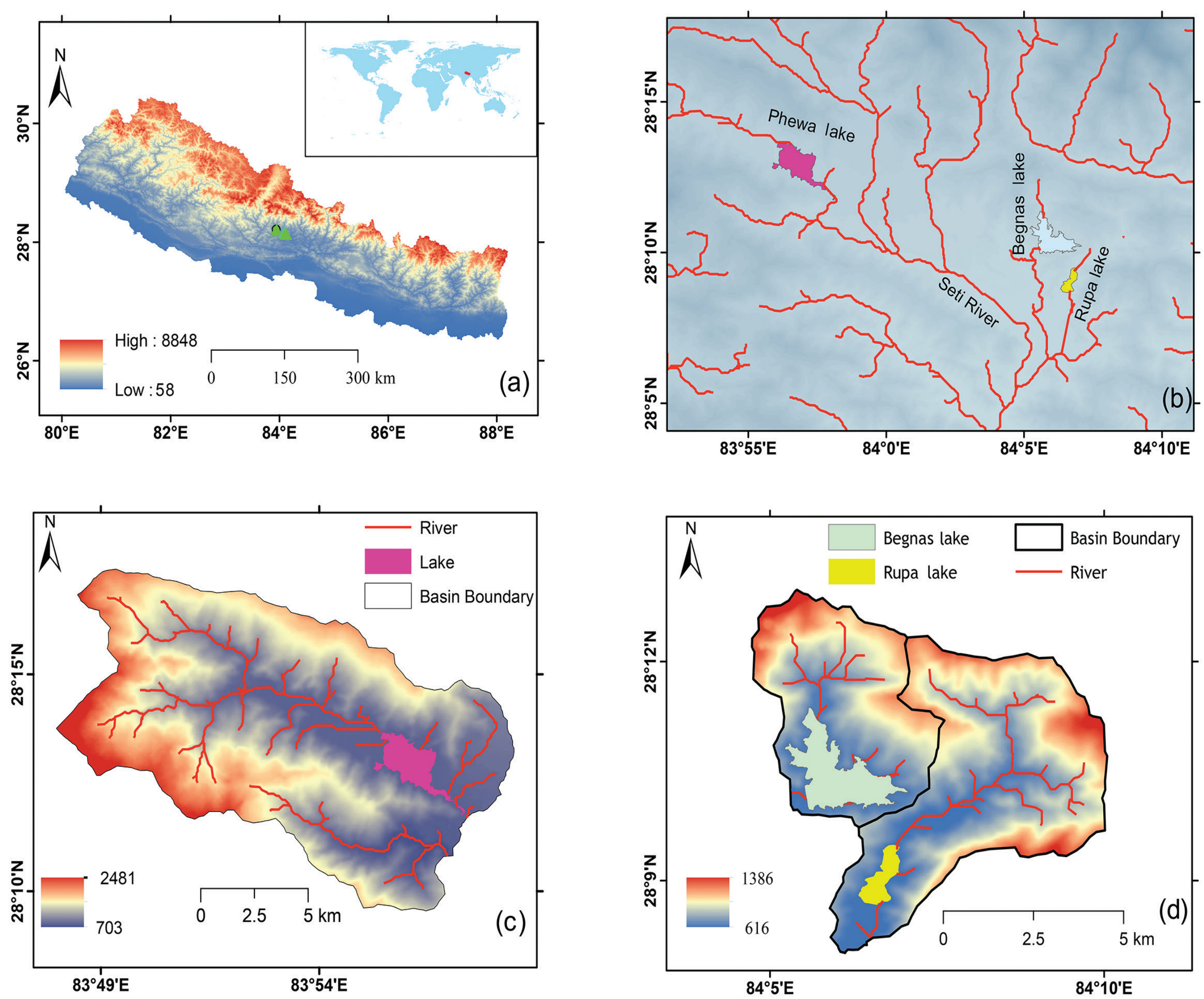

Fig. 1: Maps showing (a) study site locations (Phewa, Begnas and Rupa lake) in Nepal (b) Location of Phewa, Begnas and Rupa lake in Pokhara valley (c) The catchment of Phewa lake (d) The catchment of Begnas and Rupa lake.

METHODOLOGY

The data of lakes status were obtained from the published literature and reports. Cloud free Landsat images of 1975, 2000 and 2018 (8-operational land imager) were downloaded from the United States Geological Survey (USGS) earth explorer (https://earthexplorer.usgs.gov/) geoportal. The acquired Landsat images were of the post-monsoon period (October to December), to obtain the less cloud cover. The obtained Landsat images were found to be geometrically correct and aligned with each other at the sub-pixel level, and no pre-processing was done. After the extensive field visit and observation in February 2019, 6 types of classification schemes (forest, agriculture land, water bodies, built-up area, degraded land, and wetland) for Phewa and 5 type of classification scheme (forest, agriculture land, water bodies, built-up area, and wetland) for Begnas and Rupa lakes were applied (Table 1). The obtained images were analyzed using the ArcGIS 10.4 software. Vector polygons for predefined land classes were generated using Google Earth imagery as a reference. The vector polygons were merged and labelled into predefined land classes. The unsupervised classification was applied to get the LULC map of 2018. Similar approach was used to generate the LULC of 1975 and 2000. To minimize the error during land use classification and to make sure the classified pixel represents the ground reality, it is necessary to check the accuracy of the Landsat image. The accuracy assessment/validation of the 2018 map was done using the high-resolution imagery for 2018 from Google Earth as reference data (Congalton and Green, 2002). Similar accuracy was assumed for 1975 map because both the maps were produced using the same procedure. Also, the LULC map of 1990, 2000 and 2010 was obtained from the International Centre for Integrated Mountain Development (ICIMOD) (http://rds.icimod.org).

The climatic data of Pokhara meteorological station was obtained from the Department of Hydrology and Meteorology of Nepal. To capture the local observations on how the lakes have changed and to identify the possible mechanisms controlling the changes, key informant interview and informal discussions with the relevant stakeholders and local peoples were carried out during the field visit in February 2019.

RESULTS

Phewa lake

In 1973, a limnological investigation of the lakes around the Pokhara valley was conducted (Maeda and Ichimura, 1973) and it categorized the Phewa into a subtropical monomictic lake with seasonal thermal stratification (Chaudhary et al., 2015; Maeda and Ichimura, 1973). The pH, water temperature, and electrolytic conductivity of Phewa lake ranges from 7 to 8, 18.1 to 26.9°C and 20 to 50 µS, respectively (Maeda and Ichimura, 1973). The alkalinity and visibility were 0.06 mval/l and 0.04 mval/l (Maeda and Ichimura, 1973). The lake was extremely dynamic with advection mixing occurring during the monsoon period (Lohman et al., 1988). Lohman et al. (1988) categorized the Phewa lake as a mesotrophic lake. Due to the different air circulation system, the phytoplankton abundances changes within a year (Maeda and Ichimura, 1973). During the monsoon season (July to September) abundance of phytoplankton was low compared to pre-monsoon and post-monsoon season. Similarly, an abundance of ion concentration was also higher in the monsoon season. The *Chlorophyll a* content was found to be maximum during the winter season. Calcium accounted for 66.3% of cation concentration in Phewa lake (Lohman

Table 1: Major land use and land cover types in Pokhara valley, Nepal.

Land cover type	Description
Urban/ Built up area	Urban and rural settlements, commercial areas, industrial areas, construction areas, traffic, airports, public service areas
Agriculture land	Wet and dry croplands, orchards
Forest	Evergreen broadleaf forest, deciduous forest, scattered forest, low-density sparse forest, degraded forest, including shrub and grassland
Water body	River, lake/pond, canal, and reservoir with a permanent mixture of water
Wet land	Swampy and marsh land, Seasonally submerged in water
Degraded land	The area exposed after landslides and flash floods in higher areas, as well as areas covered in sand and debris deposited in lower areas, without any kind of vegetation or crops

et al., 1988). In 1993/1994, the annual average water temperature, pH, and light attenuation in Phewa lake were 15–29°C, 6.3–9.7, and 0.46–1.39, respectively (Rai, 1998; Rai, 2000a). In 2005, the annual concentration of nitrate+nitrite (NO_3+NO_2), soluble reactive phosphate (PO^{4-}) and total phosphorous of Phewa lake were 0.148 mg/l (mean= 0.013 mg/l), 0 to 0.003 mg/l (mean= 0.001 mg/l), and 0 to 0.052 mg/l (mean= 0.009 mg/l), respectively (Husen and Dhakal, 2009). In late 19th century, the sedimentation rate in Phewa lake was very high, about 20 mm a^{-1} (JICA, 2002; Ross and Gilbert, 1999). It has suggested that if sedimentation follows the same way, the lake will likely be disappeared within 360 years (Ross and Gilbert (1999). In recent decades, the water quality is deteriorating in Phewa lake (Rupakheti et al., 2017). The increased mercury concentration has severe impact on the fishes, macrophytes, macroinvertebrates and human health (Sharma et al., 2013; Sharma et al., 2015; Thapa et al., 2014). For example, the total mercury concentration (THg mg kg^{-1} ww) in four fish species *(Tilapia Tilapia Oreochromis niloticus, Spiny Eel Mastacembelus armatus, African catfish Clarias gariepinus, and Sahar Tor putitora)* in Phewa lake were 0.02, 0.07, 0.05, and 0.12, respectively (Sharma et al., 2013). In 2010, Phewa lake water temperature, pH, TOC, SO_4^{2+}, NO^{3-}, Cl^-, Ca, K, Mg, Na, and Si were 24°C, 7.1, 65 µS/cm, 0.8 mg/l, 1.3 mg/l, 0.3 mg/l, 1.1 mg/l, 10.3 mg/l, 3.9 mg/l, 1.7 mg/l, and 2.9 mg/l, respectively (Rosseland et al., 2016). The increased concentration of trace elements in Phewa lake has severer negative impact on aquatic species of lake. In 2017, the concentration of nitrate-nitrogen ($NO_{3-}N$) in Phewa lake were 0.187 mg/l (Das, 2017). This concentration is higher than the study conducted in 2005 (Husen and Dhakal, 2009). The study on Phewa lake area using different methods such as manual digitization, Landsat images, RapidEye imagery suggest that the lake area has changed substantially since 1926 (Watson et al., 2019). In 1926, the lake had the area of 2.44 ± 1.02 km^2, increased to 3.97 ± 0.41 km^2 in 1956/1957, 4.61 ± 0.07 km^2 in 1961, 4.75 ± 0.63 km^2 in 1972, and 4.37 ± 0.35 km^2 in 1988 (Watson et al., 2019). Water hyacinth was very common in the lake. The lake water level follows the seasonal atmospheric circulation pattern i.e., during summer monsoon, the lake has its maximum water level but the water flow is lower during winter. The lake has an annual water level fluctuation of 1.5 m (Watson et al., 2019). In recent decades, eutrophication is a major problem in the lake attributed to the increased nutrition loading from surrounding agriculture field as well as from nearby Pokhara city (Pant and Adhikari, 2019a).

Begnas lake

In 1973, pH, water temperature, electrolytic conductivity, and visibility of Begnas lake in the winter season was 8, 18.3°C to 19.08°C, 2 µS – 23 µS and 1.4 m, respectively (Maeda and Ichimura, 1973). The Dissolved Oxygen (DO) of the lake fluctuates between 0.0 and 13.9 mg/l in 1998 (Rai, 2000b). However, DO value ranges from 0 to 10.2 mg/l in 2011. The major ion concentration was higher during the post-monsoon period. The average superficial PO_4^{3-} ranges from 0.01 to 0.16 mg/l with a relatively higher during pre-monsoon and post-monsoon. From this study using Landsat image of 1976, the lake area was found 2.13 ± 0.3 km^2. In 1993/1994 the lake area increased to 3.28 km^2 (Rai, 1998). Compared to 1976 the lake area of Begnas lake has increased by 1.15 km^2 in 1993. The increased lake area between 1976 and 1993 was due to dam construction in Begnas lake during 1988.

Rupa lake

In 1976, pH, water temperature, and visibility of Rupa lake in the winter season were 7.0 and 8.3, 18.3 to 19.08°C and 1.8 m, respectively (Maeda and Ichimura, 1973). Landsat Multispectral Scanner Image analysis the lake area was found to be 1.22 ± 0.15 km^2 in 1976. The highest temperature gradient in the water column of Rupa lake was found 2.0°C lake area of Rupa lake was found to be 1.17 km^2 in 1988 and 1.07 km^2 in 2011(Dhakal et al., 2012). In 1988, the lake had an average depth of 12.3 m, which declined to 1.9 m in 2011. In 2012, Rupa lake had average Nitrogen content and PO^{4-} as 0.146 ± 0.025 mg/l and 0.004 ± 0.00 mg/l, respectively. In recent decades, eutrophication is the major problem in all the Phewa, Bengas and Rupa lakes (Pant and Adhikari, 2019; Pant et al., 2019). Extensive colonization of invasive alien plant species such as *water hyacinth*, *parthenium*, *morning glory* and *lantana camera* in all the three Phewa, Begnas and Rupa lakes were observed during the field visit.

Land use and land cover change

Land use and land cover change in the catchment of lakes Phewa, Begnas and Rupa is shown in Figure 2 and summarized in Table 3. Overall, from 1975 to 2018, the forest cover in all the three lakes catchment has decreased. Agriculture land in Phewa lake catchment has increased between 1975 and 2018. In the case of Begnas and Rupa lakes catchment agriculture land is nearly stable, comparing the overall trend from 1975 to 2018. In all the three lakes catchment, there is a significant increase in the agriculture land from 1975 to 2000 while decreased from 2000 to 2018. From 2000 to 2018, the change in the built-up area in Phewa lake catchment is relatively high (4.63%) as compared to that in Rupa (2.07%) and Begnas (0.2%).

Table 2: Summary of changes in status of Phewa, Begnas and Rupa lakes in Pokhara valley, Nepal with time after 1973.

S.N	Parameters	Phewa lake				Begnas lake				Rupa lake			
		1973	1982	1993/1994	2009**/2011	1973	1988	1993/1994	2011	1973	1988	1993/1994	2011
1	Surface area (Sq km)	5[a]		5.23[b]	4.11[d]	2.5[a]		3.28[b]		1.4[a]	1.17[d]	1.3[b]	1.07[c]
2	Water Volume (MCM)	…		39.32*10^6[b]	….			17.96*10^6[b]			2.7[b]	3.25*10^6[b]	2.08[c]
3	Maximum depth (m)	23[a]		24[b]	….	8[a]		10[b]		4[a]	4.5[d]	6[b]	3.52[c]
4	Average depth (m)	6[a]		7.5[b]		4.6[a]		6.6[b]			2.03[d]	3[b]	1.95[c]
5	Visibility (m)	1.7 to 4.7[a]	0.63 to 1.02[d]	2 to 8.4[b]	1.7 to 3.8[d]	1.4[a]				1.8[a]			
6	pH	6.4 to 6.6[a]		6.3 to 9.7[b]		8[a]		6 to 10.1[b]	7.27[c]	7.3 to 8.3[b]		5.4 to 8.7[b]	
7	DO (Mg/l)			0 to 12.3[b]	0.0 to 9.7[d]			0 to 13.9[b]	8.82[c]			0.6 to 9.2[b]	
8	NH_4^{+1} (mg/l)			0 to 0.4[b]	0.0 to 0.021[d]			0.0 to 2.0[b]				0 to 0.24[b]	
9	Particulate carbon (mg/l)			0.45 to 4.44[b]				0.67 to 4.38[b]				0.25 to 3.69[b]	
10	Particulate Nitrogen (mg/l)		0.11 to 0.54[d]	0.06 to 0.52[d]			0.008 to 0.69[d]	0.07 to 0.71[b]			0.06 to 0.4[d]	0.03 to 0.72[b]	
11	Particulate Phospho-rous (mg/l)		0.07 to 0.010[d]	0.07 to0.054[d]			0.004 to 0.009[d]	0.004 to 0.054[d]			0.004 to 0.01[d]	0.007 to 0.069[b]	

Sources: a = (Maeda & Ichimura, 1973), b = (Rai, 1998; Rai, 2000b), c = (Kunwar & Devkota, 2012), d = (Ferro, 1978; Khadka & Ramanathan, 2012; Lohman et al., 1988).

Table 3: Land use and land cover change in catchments of Phewa, Begnas and Rupa lakes.

	(%) Area								
Land use	Phewa			Begnas			Rupa		
	2018	2000	1975	2018	2000	1975	2018	2000	1975
Forest	39.64	39.89	52.71	50.33	44.56	57.1	68.46	65.02	70
Agriculture land	45.19	49.71	44.01	31.16	38.26	31.96	24.72	30.14	25.74
Built up area	9.28	4.65	0	2.2	2.04	0	2.9	0.83	0
Water Bodies	3.13	4.01	3.13	13.29	14.53	10.6	3.7	3.6	4
Wet land	0.77	0.14	0.14	3.02	0.59	0	0.18	0.4	0.29
Degraded land	1.98	1.57	0	–	–	–	–	–	–

The analysis of land use map of 1975 suggests that forest occupied the highest percentage, i.e., 52.72% of the land in Phewa lake catchment, and it is followed by agricultural area (44.01%), water body (3.13%) and wetland (0.14%). In 2000, the land use pattern changed drastically compared to 1975. In 2000, forest cover, agriculture area, water bodies, wetland, built-up area and barren land occupied 39.89%, 49.71%, 4.01%, 0.14%, 4.65% and 1.57%, respectively. Compared to 1975, the forest area had decreased in 2000, while the agriculture land and water bodies were increased (Fig. 2). From 2000 to 2018, the forest has slightly increased, while the built-up area increased dramatically from 4.65% to 9.2%. Also, wetland and degraded land increased in 2018. In 2018, agricultural land and water bodies decreased compared to 2000.

In 1975, Begnas lake catchment was occupied by 57.1% of forest land, followed by 31.9% agriculture land and 10.6% water body. In 2000, the forest area decreased to 44.56%, whereas agricultural land and water body increased to 38.26% and 14.53%, respectively. The forest, built up and wetland areas in the lake catchment were increased to 50.32%, 2.2%

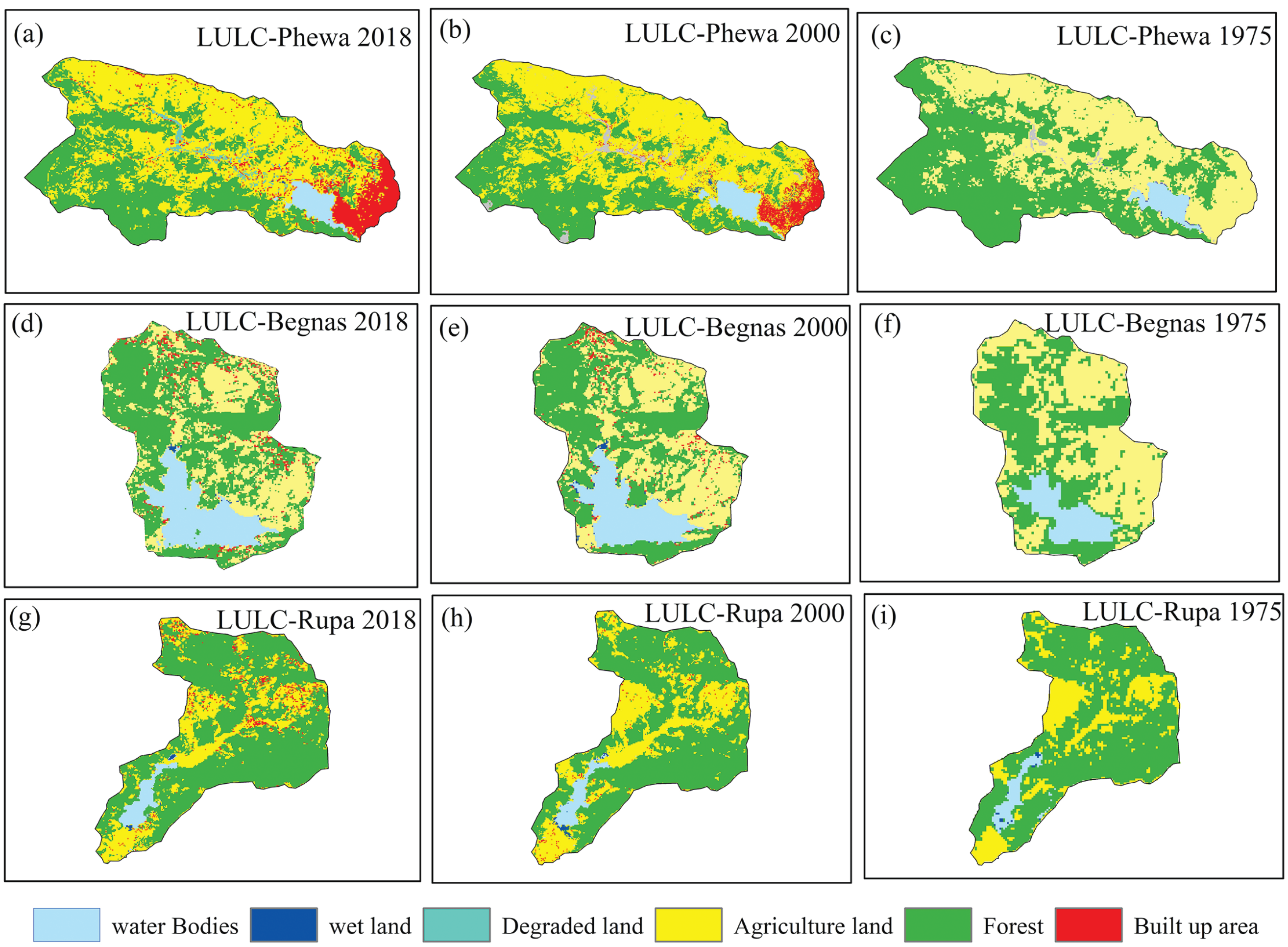

Fig. 2: Land use map of the catchments of lake Phewa: (a) 2018 (b) 2000, and (c) 1975; lake Begnas: (d) 2018 (e) 2000, and (f) 1975; lake Rupa: (g) 2018 (h) 2000, and (i) 1975.

and 3.1%, respectively. However, agricultural land and waterbodies decreased to 31.16% and 13.29%, respectively.

In Rupa lake catchment, the forest had occupied the highest percentage of land (70%), and was followed by agricultural land (25.74%) and water bodies (4%) in 1975. From 1975-2000, the forest area decreased to 65.01% in the lake catchment, whereas the agriculture activities increased to 30.14% (Table 3). This suggests that forest land converted into agricultural land. From 2000 to 2018, the forest land, built-up area, and waterbodies increased to 68.45%, 2.90%, and 3.7%, respectively, whereas the agriculture and wetland decreased to 24.72% and 0.18%, respectively. The increased forest areas suggest the proper environmental management in the lake catchment. The trends of LULC changes in Phewa, Begnas and Rupa lake catchments between 1975 and 2018 are shown in Fig. 3.

Climate Change

Temperature and precipitation data for 1971-2017 were analyzed to understand the Pokhara valley do experienced changes in climatic parameters with time. The average maximum and minimum temperature trends have increased at a rate of 0.008 and 0.026 degrees per annum during 1971-2017. The maximum and minimum temperatures were recorded in 2006 and 2009, respectively. The maximum and minimum temperature trends in the Pokhara valley are consistently increasing and are consistent with other studies (Baidya et al., 2008; Shrestha et al., 1999; Shrestha and Aryal., 2010).

The average total annual precipitation was 3863.29 mm during 1980 –2016, with maximum precipitation in July and the lowest precipitation in December. The total annual precipitation suggests that maximum precipitation occurred in 1998, whereas the lowest

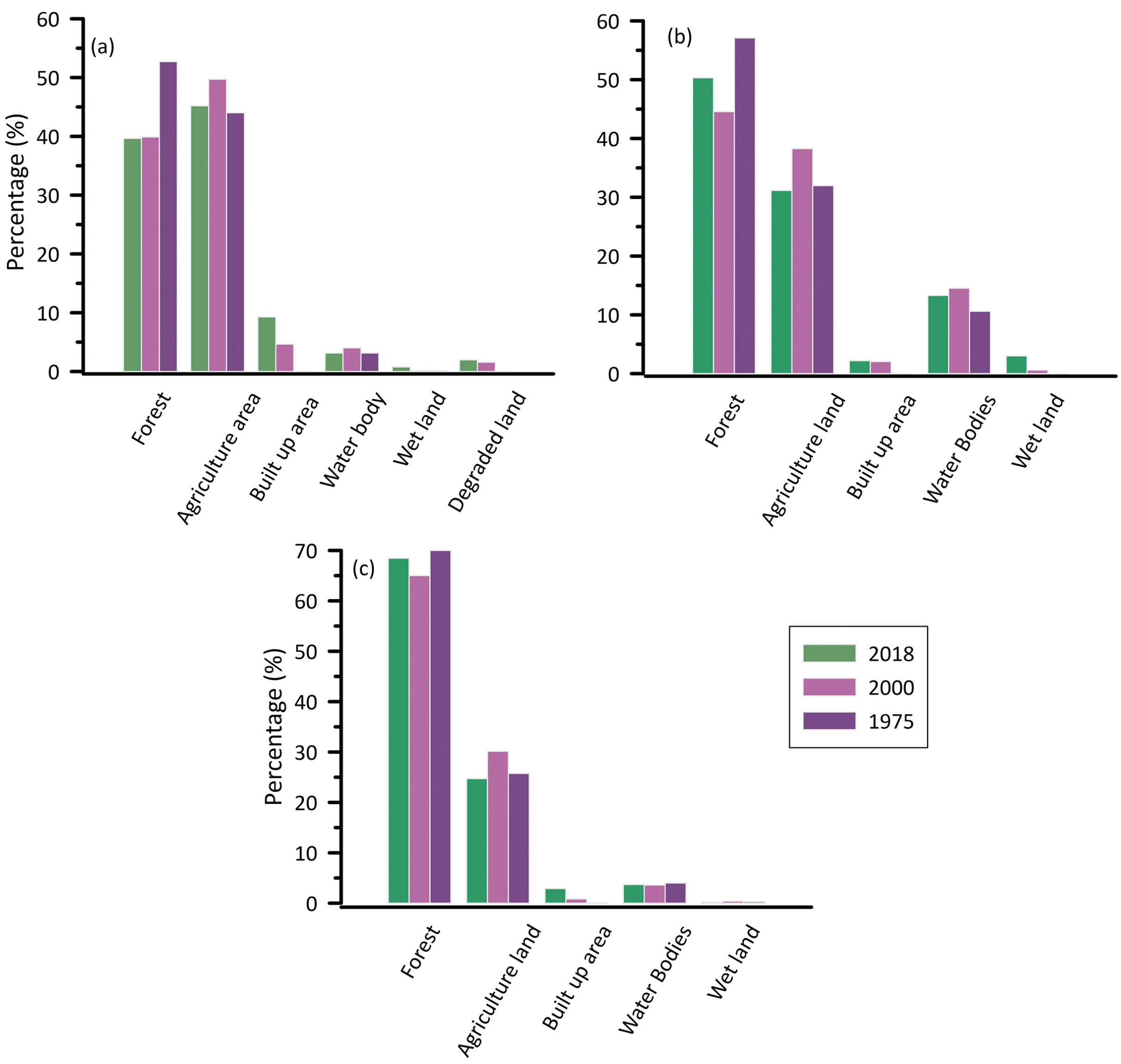

Fig. 3: Trend of LULU change from 1975-2018. (a) Phewa lake (b) Begnas lake and (c) Rupa lake catchments, Pokhara.

precipitation occurred in 1992. The precipitation trend has shown increased from 1980 to 2000, whereas the precipitation has decreased from 2000 to 2018.

DISCUSSION

Understanding of ecological responses to the LULC change in the catchment of the lake is vital to understand how the aquatic ecosystems respond to human activities. Such studies in the local and regional levels provide evidence for environmental management plans, policies, and programs. Such studies are also important for ecosystem restoration and sustainable resources management (Rimal et al., 2019). Therefore, time series analysis of lakes status and LULC change in the catchment are important.

The decrease in the forest cover and an increase in the agricultural land are the significant changes observed in Phewa, Begnas and Rupa lakes catchment from 1975 to 2000. The decrease in the forest area in the Phewa, Begnas and Rupa lakes catchment during this period was also observed in the national forest coverage record of Nepal. In Kaski district, the decreased forest cover from 1988 to 2000 was also reported by (Rimal et al., 2018). From 2000 to 2018, the forest area increased in all the lake catchments similar to other records from Nepal, such as the Koshi basin in eastern Nepal (Rimal et al., 2019; Shrestha et al., 2019). The decreased forest cover and increased agriculture land are observed from 1990 to 2000 while analyzing the LULC map of lakes catchment from ICIMOD using the National data sets.

Similarly, the increased forest cover, decreased agricultural land and an increased built-up area were observed from 2000 to 2010 from the map from ICIMOD. The LULC assessment of Kaski district from 1988 to 2016 showed a significant increase in the built-up area after 2000 (Rimal et al., 2018). The considerable change in the built-up area in the Phewa lake catchment is likely due to the presence of urban center (Pokhara city) near Phewa lake. After the formation of Siddhartha highway, Pokhara have been the important tourist hub of Nepal. Increasing tourism activities likely attracts the peoples from the rural part to migrate nearby Pokhara for different opportunities, which fueled the increase in the built-up area in Phewa lake catchment from 2000 to 2018. Likewise, increasing population and Tourism activities may have caused the increased built-up area in Begnas and Rupa lakes catchment.

LULC change in the catchment of lakes can have a significant impact on the aquatic ecosystem by altering the nutrients input, sediment loading and hydrological flow regimes (Malthus and Mitchell, 1988; Soranno et al., 1996; Jamu et al., 2003). In this study, lake water pH of Phewa lake has increased from 6.4–6.6 in 1974 to 6.3–9.7 in 1993/1994 (Maeda and Ichimura, 1973; Rai, 2000b). In 2005, nutrient concentration (nitrate+nitrite, soluble reactive phosphate, total phosphorous) in Phewa lake was higher than the previous studies (Rai, 1998; Rai, 2000a). The lake area has decreased sharply from 1992 to 1994, which is likely due to anthropogenic activities in the lake catchment (Ross and Gilbert, 1999). Similar changes are observed in Bengas and Rupa lakes. The pH value of the Bengas lake decreased ranging from 7.0 to 7.7 in 2012 with a peak value during the pre-monsoon season (Khadka and Ramanathan, 2012). In the winter season of 2012, pH of the Bengas lake was found to be 6.7–7.6 (7.0 ± 0.2) (Khadka and Ramanathan, 2012), which was lower than the previous studies (Maeda and Ichimura, 1973; Rai, 2000b). Lower pH value in 2012 compared to 1973 and 1993 suggests lake was more acidic in 2012. Compared to 1998 DO value of the Begnas lake has decreased in 2011 (Khadka and Ramanathan, 2012). PO_4^{3-} values in recent years is higher than the past decade (Khadka and Ramanathan, 2012). In the case of Rupa lake the concentration of particulate phosphorous and particulate nitrogen was higher in 1992/1993 than in 1973. Such changes in the lakes environment was believed to be because of the changes in land use pattern and sediment and nutrient loading into the lake. The lake area has decreased gradually by 0.08 km^2 from 2000 to 2018 (Watson et al., 2019). A significant increase (~60%) in lake area between 1926 and 1956/1957 was observed attributed to the dam construction in 1933. From 1975 to 2000 sediment loading into the Phewa lake was higher than from 2000 to 2018 (Ross and Gilbert, 1999; JICA, 2002; Watson et al., 2019). The higher sediment loading from 1975 to 2000 is likely attributed to the decreased forest cover in the lake catchments.

An increased forest cover can reduce sediment loading into the lake (Watson et al., 2019). Similarly, an increase in the agricultural land in the catchment enhances the nutrient delivery into the lake, fueling the aquatic production in the lake (Carpenter et al., 1999). The increase in the agriculture land in the Phewa, Begnas and Rupa lakes catchment may have increased the aquatic production in the lake. However, this study could not establish how the increase in the agricultural land impacted the lake ecosystem. The rapid growth in the aquatic plants in Phewa, Begnas and Rupa lakes likely linked to the increased nutrient delivery from the agriculture activities (Kunwar and Devkota, 2012; Chaudhary et al., 2015). From 2000 to 2018, the physical properties such as water temperature, dissolved oxygen, transparency, pH, light attenuation, chlorophyll-*a*, and nutrients level of Phewa, Begnas and Rupa lakes had increased compared to pre-2000 (Rai, 2000b). The water quality of the lake decreased (Rupakheti et al., 2017), along with the increased mercury concentration (Sharma et al., 2013;

Thapa et al., 2014). The fish production in the lakes decreased (Chaudhary et al., 2015). Such changes in the lake environment can be linked to human induced LULC change in the lake catchment. From 2000 to 2018, the built-up area in the Phewa, Bengas and Rupa lakes catchment increased, which may be the primary driver for the lake environment change during that time. Similar findings were observed in Jilin province of southern China, increased farm land and built up area have decreased the wetland, water bodies and grassland (Li et al., 2015). Hongze lake, Jiangsu province, China water bodies were affected by the land cover changes (Ruan et al., 2008). The wetland area in Harika wetland, India shrunk by 13% in just 20 years following the rapid agriculture expansion in the catchment (Mabwoga and Thukral, 2014).

From 1980 to 2016, the minimum temperature in Pokhara airport meteorological station has increased by almost 1^0C, which can have some impacts on lake environments of the Phewa, Begnas and Rupa lakes. However, from this study, it is challenging to predict the impact of climate change on these lakes environment. The algal bloom observed during the field visit to the lake is likely from the combined effect of both climate change and human activities. Similar findings were observed in Ghodaghodi lake, western Nepal where, ecological degradation has been much prevalent due to anthropogenic pressure and climatic change (Lamsal et al., 2019). Further studies are necessary to understand how climate change is affecting the lakes in Pokhara.

CONCLUSIONS

This study presents the impact of LULC change in the catchment on lake environments of the Phewa, Begnas and Rupa lakes, central Nepal. Overall, from 1975 to 2018, the forest cover has decreased, the built-up area has increased and agricultural land remained nearly stable in Phewa, Begnas and Rupa lakes catchment. During that time, lake environment of these lakes changed significantly in terms of sedimentation rate, physio-chemical parameters and biological environment. From 1975 to 2000, the forest cover in these lakes has decreased, whereas the agricultural land has increased. During the same period, the sedimentation rate in the lake was high. The changes in the sedimentation rate in the lake environment is possibly by the decrease in the forest cover together with anthropogenic activities in the catchment of the lake. From 2000 to 2018, forest cover and built-up area in these three lakes has increased, whereas agricultural land has decreased. During 2000 to 2018, the sedimentation rate in the lake has decreased compared to during 1975 to 2000. Reduced sediment loading into the lakes during 2000 to 2018 is attributed to the increased forest cover in the lake catchment. From 1971 to 2017, the minimum temperature of Pokhara risen by about 1^0C, which might have made a significant impact on the lake environment.

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