ISSN 2392-4705
URL: http://www.doenv.gov.np

JOURNAL OF ENVIRONMENT SCIENCES

(JoEnvSc)-Volume VIII, 2022

Government of Nepal
Ministry of Forests and Environment
Department of Environment

Editorial Board

Printing: Swetkali Chhapakhana
Lagan, Kathmandu
01-4262600, 4269309

Date of Publication, 2022 July

Department of Environment (DoEnv)
Babarmahal, Forestry Complex, Kathmandu, Nepal
Tel: 01-5320837/01-5320497 Email- info@doenv.gov.np
ISSN:2392-4705
The issue can be retrieved from http://www.doenv.gov.np

Editorial

It is our pleasure to bring out the current issue of Journal of Environment Sciences. Ten articles on different thematic areas and cross cutting issues have been included here. Environmental knowledge generated in environmental sectors by different researchers, GOs/NGOs/INGOs, academic institutions has been assembled in the form of Journal of Environment Sciences, Volume VIII, 2022 as our yearly publication.

Journal of Environment Sciences aims to share environmental information and also promote to establish link among professionals, researchers, academicians and policy makers by providing them a common platform for further coordination and cooperation. We believe that the findings, outcomes, and suggestions obtained from these researches could serve for betterment of society and help to achieve environmental governance. We also believe that this journal will further help to pile up the scattered knowledge, information, techniques, technologies that have been generated in different paradigm of environment.

We want to assure here that the views expressed in the articles are those of authors and do not represent the official views of the Department of Environment. We acknowledge the valuable contribution from authors, researchers, reviewers and other human resources of the Department of Environment to continue this publication. With your cooperation, coordination and feedback, this Journal will remain uninterrupted.

Thank you
Editorial Board

Table of Contents

Vegetation Assemblage and Carbon Stock in the Sacred Groves of Kathmandu Valley, Nepal

Hari Sapkota[1,2], Narayan Babu Dhital[3], RoshaniManandhar[2], Ramesh Prasad Sapkota[1*]
[1]Central Department of Environmental Science, Tribhuvan University, Nepal
[2]Department of Environmental Science, Amrit Campus, Tribhuvan University, Nepal
[3]Department of Environmental Science, Patan Multiple Campus, Tribhuvan University, Nepal
*Corresponding email: rsapkota@cdes.edu.np

Abstract

Sacred groves (SG) play crucial roles in maintaining vegetation diversity and storing carbon. In Nepal, there is relatively little information about the carbon sequestration potential of SGs compared to other forest types. To address this research gap, this study analyzed the vegetation assemblage and carbon stock in three SGs, namely Bajrabarahi, Mhepi, and Swayambhu forests, located in the Kathmandu Valley. Systematically distributed square plots (15 m × 15 m) were used as sampling units. Above-ground tree biomass and below-ground tree biomass were estimated by using the allometric equation of trees, considering the diameter, height, and specific gravity of wood. A total of 479 individuals of woody species belonging to 37 species were recorded from the three SGs. Species diversity and species richness were relatively higher in SwayambhuSG. Based on the importance value index, Celtis australis, Schimawallichii, and Neolitseacuipala were dominant in Mhepi, Swayambhu, and BajrabarahiSGs, respectively. Total biomass and carbon stock were highest in the BajrabarahiForest and lowest in the SwayambhuForest. The average biomass and carbon stock in the three urban SGs were approximately 405 ton/ha and 191 ton/ha, respectively. The findings of the present study suggested that maintaining vegetation assemblage, biomass, and carbon stock in SGs might have important contributions to sequestering carbon, conserving biodiversity, and enhancing the aesthetic values of the religious areas.

Keywords: *Above-ground tree biomass; Below-ground tree biomass; Carbon sequestration;Importance value index; Vegetation diversity*

Introduction

Carbon is an important component of life on Earth. Green plants havethe unique ability to absorbCO_2 from the atmosphere and assimilateit in the form of organic carbon during photosynthesis. Forests can be managed to sequester or conserve significant amounts of carbon on the land (Brown et al., 1996).Forest ecosystems play crucial roles in regional and global carbon cycles due to their capacity to store large quantities of carbon in different pools,exchange carbon with the atmosphere through photosynthesis and respiration, and become carbon sinks throughthe restoration of degraded forests. However, depending on the management activities, forests can act as both carbon sinks as well as sources. By protecting and conserving carbon pools in existing forests, the goal of lowering carbon dioxide emission and increasing carbon sinks may be accomplished efficiently(Brown & Schroeder, 1999).

Sacred groves (SG) are forest patches conserved by local people of certain localities based on their indigenous cultural and religious beliefsthat the deities reside in them (Khumbongmayum et al., 2006). They vary in size and are protected by local communities as being the sacred residences of local deities (Saikia, 2006). Sacred forests are one of the oldest forms of conserved natural forest (Pala et al., 2013) and, therefore, contribute substantially to biomass carbon stock management (Waikhom et al., 2018). The sacred forests have a significantly higher percentage of tree cover, higher biodiversity, and greater biomass than the forest that do not contain a sacred site (Lynch et al., 2018). AnSG not only provides habitat to biodiversity but also plays a major role in carbon cycling (Sharma et al., 2019).

In Nepal, 40.36% of the total land surface iscovered by forest, and 4.38% by other wooded land(DFRS, 2018). According to FRA (2020),approximately 2000 ha of the land area is covered by religious forests in Nepal. The SGs managed by local communities also serve an important role in the protection of plant biodiversity and the sequestration of atmospheric carbon (Shrestha et al., 2016a). Furthermore, well-protected sacred forests, because of their higher biomass, sequester significantly more carbon compared to other forest ecosystems (Vikrant et al., 2019).

Nepal is a culturally rich country, where many societies conserve forestsfor various religious purposes(Shrestha et al., 2016b). Although SGs are ecologically and religiously important, they are alsounder pressure from overharvesting of fuelwood, timber, fodder, and overgrazing of cattle (Bhattarai & Baral, 2004). In Nepal,limited studies are carriedout inSGs. Among them, very few studies are done on vegetation assemblage and carbon stock (Nepali et al., 2015; Sharma et al., 2018; Shrestha et al., 2016a).So, there is relatively little information about the carbon sequestration potential of the religious forest when compared with other forest types. With this background, the present study was carried out in three SGs of the Kathmandu Valley with the main aim toassess the vegetation assemblage and estimate carbon stock in the major carbon pools. The findings of the present study would be valuable to understand the role of SGs located in the Kathmandu Valley in protecting biodiversity, regulation local environment, and sequestering carbon.

Materials and methods

Study area

The study was conducted in three SGs of the Kathmandu Valley, in the Mid-Hillzone of Central Nepal (Figure 1).BajrabarahiSG (18.29 ha) is located at the southeast corner of the Kathmandu Valley in the Lalitpur District at an altitude of 1440 maslandlies between 27°36′11.07″N to 27°36′28.65″N latitude and 85°19′38.77″E to 85°20′1.06″E longitude.Bajrabarahi is the religious temple that lies in this forest.Likewise, MhepiSG (1.65 ha) islocated in Kathmandu City at an altitude of 1323 masland lies between 27°43′36.05″N to 27°43′41.10″N latitude and 85°18′27.57″E to 85°18′33.98″E longitude.A templeMhepiAjimais situated at the top of the hill in the MhepiSG. Similarly, SwayambhuSG(25 ha) is also located in Kathmandu City at an altitude of 1390 masland lies between 27°42′47.10″N to 27°43′5.49″N latitude and 85°17′1.43″E to 85°17′35.92″E longitude. The SwayambhuStupa, a Buddhist Monastery and a UNESCO world heritage site,is located at the top of the SwayambhuSG. The climatic pattern of the valley is warm temperate with rainy summer and dry winter (Pokharel & Hallett, 2015). The temperature of the valley varies from below 0˚C during winter to above 30˚C during summer. The average annual rainfall exceeds 1480 mm. Early June to late September is considered the heavy monsoon period for the Kathmandu Valley (http://daolalitpur.gov.np; http://dccbhaktapur.gov.np; http://dccktm.gov.np).

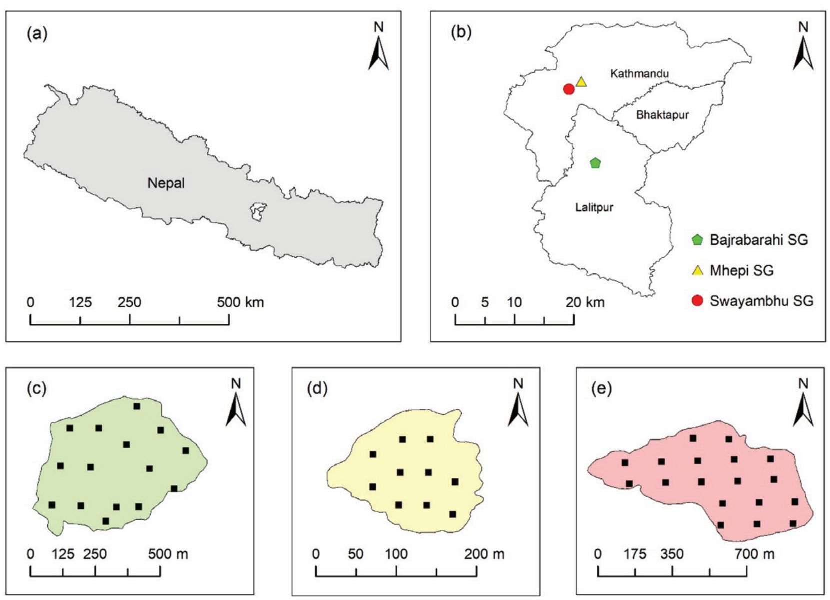


Figure 1.Study area map: (a) location of the Kathmandu Valley in Nepal, (b) location of the studied SGs in the Kathmandu Valley, (c) sampling points in Bajrabarahi SG, (d) sampling points in Mhepi SG, and (e) sampling points in Swayambhu SG.

Sampling strategy

The field study was carried out in October 2019. Data were collected usingsquare plots of area 225 m^2 (15 m×15 m)laidalong parallel transectsat an interval of 100 m in BajrabarahiSG and Swayambhu SG and 30 m in MhepiSG. Plots were constructed at 150 m intervals along each transect. The total number of sampling plots was 43, of which Bajrabarahi, Mhepi, and Swayambhu SGs comprised 15, 10, and 18 plots, respectively. Using the above criteria, sampling plots were designed on Google Earth and were located in the field using aGlobal Positioning System device. In each plot, the diameter at the breast height (DBH) and the height of individual woody species were measured using a diameter tape and a Silva clinometer, respectively. Each woody species was marked individually to prevent double counting.

Data analysis

The collected data were analyzed to estimate vegetation composition and biomass followingNewton (2007).The importance value index (IVI) of individual woody species was calculated by adding the relative values of frequency, density, and basal area using Eq. (1).

$$IVI = RD + RF + RBA \quad \text{Eq. (1)}$$

In Eq. (1), RD, RF, and RBA represent relative density, relative frequency, and relative basal area, respectively. Likewise, the basal area (BA) of woody species was calculated usingEq. (2).

$$BA = \pi d^2/4 \quad \text{Eq. (2)}$$

In the above equation, d is DBH of a woody species measured at 1.4 m from the ground surface. Similarly, the woody species diversity of the forest community was calculated using Shannon Diversity Index as shown in Eq. (3).

$$\bar{H} = \sum_{i=1}^{n} p_i \ln p_i \quad \text{Eq. (3)}$$

Where, p_i represents the importance of the i^{th} species calculated as the ratio of the number of individuals of the i^{th} species to the total number of individuals of all the species, and n is the total number of species.

The above-ground biomass of trees (AGTB) was calculated using an allometric equation developed by Chave et al. (2005) (Eq. 4).

$$AGTB = 0.0509 \cdot d^2 \cdot h \cdot \rho \quad \text{Eq. (4)}$$

In Eq. (4), AGTBis above-ground tree biomass (kg), d is DBH (cm), h is tree height (m), and ρ is the specific gravity of wood (g/cm^3). The wood-specific gravity values were taken from (Sharma & Pukkla, 1990). The total AGTB of each sampling plot was divided by the area of the plot with appropriate conversion factors to obtain AGTB in ton/ha. Then, the carbon stock was estimated using AGTB with the assumption that carbon comprises 47% of AGTB.For estimating below-ground biomass (BGB), a root-to-shoot ratio of 1:5 recommended by MacDicken (1997) was used,whichmeans that BGB comprises 20% of the AGTB.Finally, descriptive statistics were calculated for the vegetation parameters of the SGs. ANOVA was used for mean values comparison of different vegetation parameters across the forests. All statistical analyses were conducted in R version 3.3.0 (R Core Team, 2016).

A limitation of the present study is that it did not consider carbon stocks in dead wood and stumps,above-ground sapling biomass (DBH ≤ 5 cm), leaf litter, grass and herbs biomass, and soil. Nonetheless, it has been suggested that any carbon pool that does not contribute significantly to the total carbon stock can be ignored (ANSAB et al., 2010).

Results and Discussion

Vegetation characteristics

A total of 479 individuals of the woody species belonging to 37 species were identified within the sampled groves. The number of woody species were 13, 15 and 19 in Bajrabarahi, Mhepi, and Swayambu SGs, respectively (Table 1).Shannon index of diversity was found highest (2.4) in Swayambhu SG, followed by Mhepi (2.3), and Bajrabarahi (2.1) SGs.In contrast, the evenness index was found highest (0.9) in Mhepi SG, whereas the value was similar (0.8) for eachBajrabarahi and Swayambhu SGs.

Table 1.Woody species diversity and characteristics in the three SGs.

Vegetation Parameter	Bajrabarahi SG	Mhepi SG	Swayambhu SG
Species richness	13	15	19
Shannondiversity index	2.1	2.3	2.4
Evenness Index	0.8	0.9	0.8
Density(individual/ha)	494.8±22.5	502.2±39.7	479.0±23.7
Basal area (m^2/ha)	67.77±7.8	46.87±11.4	51.83±3.2
DBH (cm)	33.3±2.0	28.2±1.9	31.6±1.3
Height (m)	14.81±0.56	11.28±0.67	9.37±0.37

The average woody species density in Bajrabarahi SG was 494.8 ± 22.5individuals/ha (Table 1).Likewise, the average woody densities were502.2 ± 39.7and 479.0 ± 23.7 individuals/ha in Mhepi and Swayambhu SGs, respectively. Difference was not observed in the mean densities of woody species between the forests (Figure 2).

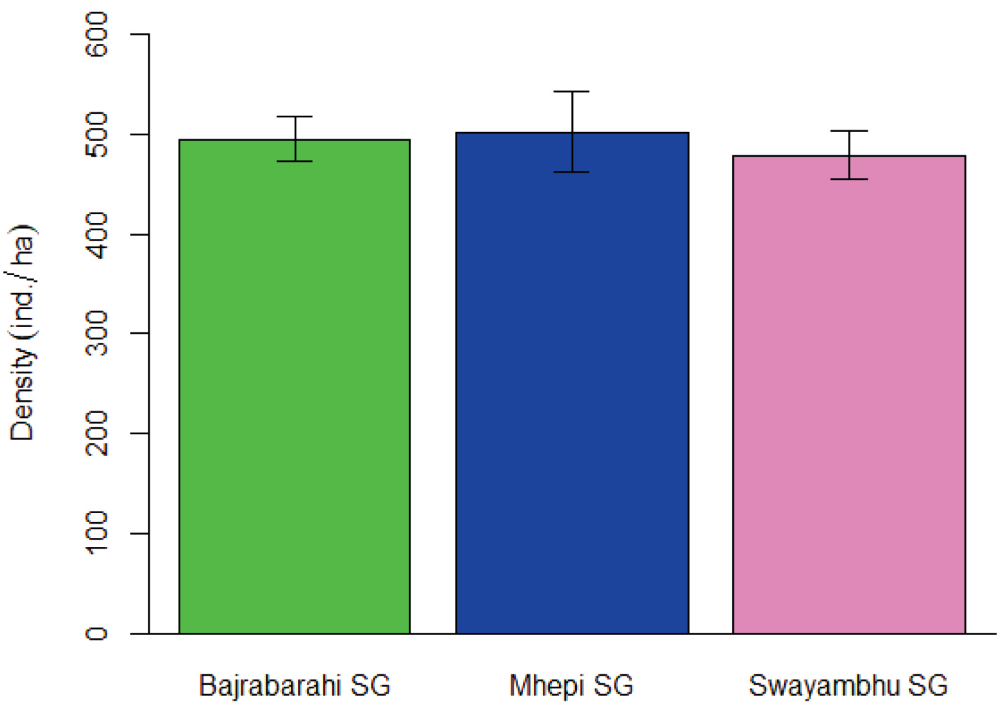


Figure 2. Meanwoody species density in the studied forests.

In Bajrabarahi SG, the average height and DBH of woody species were 14.81 ± 0.56 m and 33.3 ± 2.0 cm, respectively (Table 1). Likewise, in Mhepi, the average height and DBH of woody species were 11.28 ± 0.67 m and 28.2 ± 1.9 cm, respectively. The average height and DBH of woody species in Swayambhu SG were 9.37 ± 0.37 m and 31.6 ± 1.3 cm, respectively. Both woody species height and DBH were relatively higher in Bajrabarahi SG compared to Mhepi and Swayambhu SGs.Statistical tests revealed a significant difference in the average height of woody species between the forests ($p < 0.05$).Figure 3 compares the frequency distribution of woody species DBH in three SGs. In all SGs, the most dominant DBH class was 10–30 cm. The frequency of large-sized woody species was relatively higher in Bajrabarahi SG, compared to the Swayambhuand MhepiSGs. However, the overall DBH distributions of woody species in three SGs were similar (Figure 4), and the average DBH of tree specieswas not statistically significantly different between the SGs ($p = 0.156$).

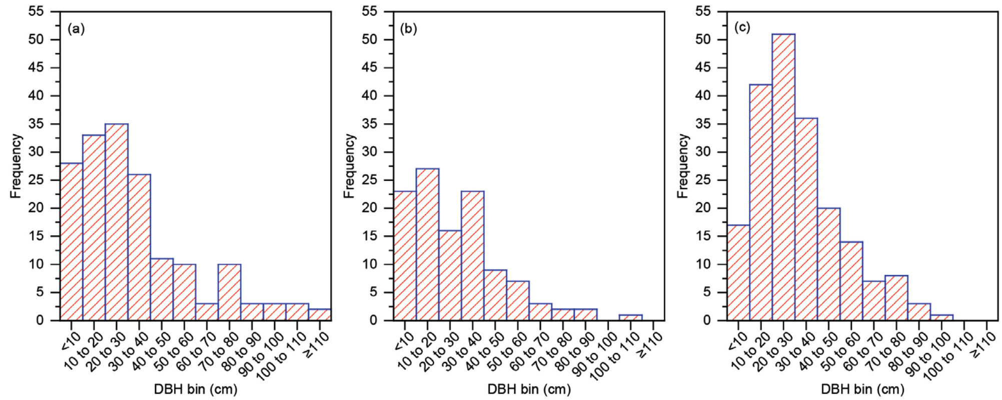


Figure 3. DBH distribution of woody species in (a) Bajrabarahi SG, (b) Mhepi SG, and (c) Swayambhu SG.

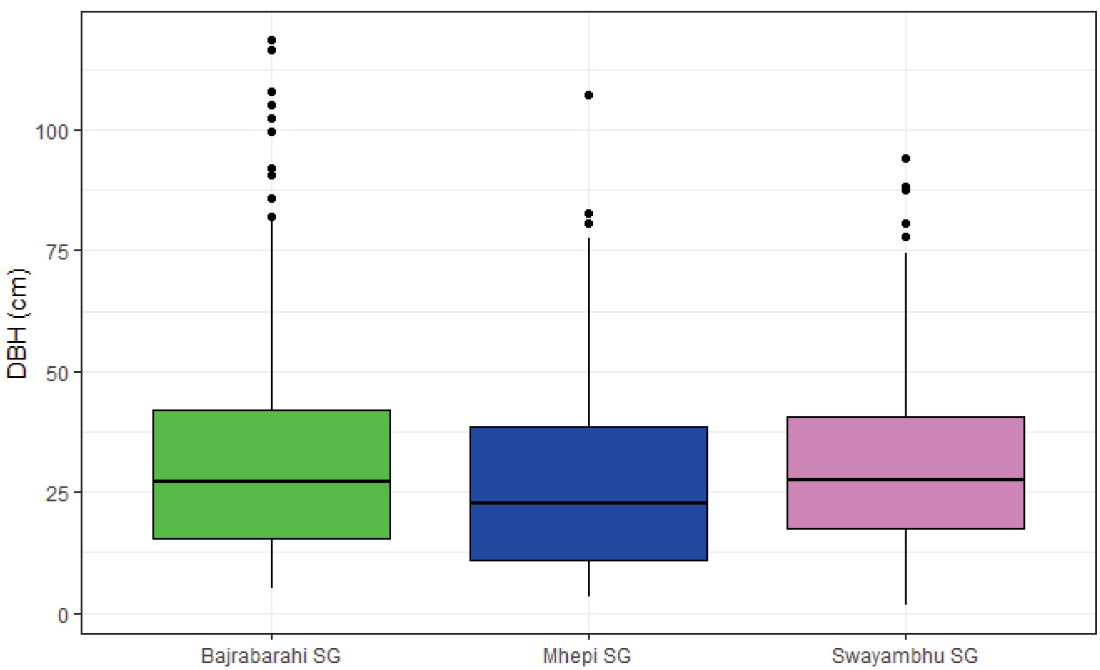


Figure 4.DBH distribution of woody species in the studied forests.

The average basal areawasfound highest (67.77 ± 7.8m^2/ha) in Bajrabarahi SG, followed by Swayambhu(51.83 ± 3.2 m^2/ha) and Mhepi(46.87 ± 11.4m^2/ha) SGs (Table 1).The highest average basal area observed in Bajrabarahi was due to the higher frequency of large-girth treespecies in this SG compared to other two SGs (Figure 3). However, the difference in the average basal area was not statistically significant among the three SGs ($p = 0.16$).

Table 2 compares the IVI and carbon stock of different woody species between Bajrabarahi, Mhepi, and Swayambhu SGs. Among all woody species recorded in Bajrabarahi SG, *Neolitseacuipala* (IVI = 80.45) was found to be the most dominant woody species, followed by *Schimawallichii* (IVI = 61.86), whereas *Pyrus pashia* (IVI = 2.75) had the lowest IVI. Similarly, in Mhepi SG, *Celtis australis* (IVI = 53.90) was found to be the most dominant woody species, followed by *Sapindusmukorossi*(IVI = 48.01), whereas the lowest IVI was obtained for *Bauhinia variegata* (4.03). In Swayambhu SG, *Schimawallichii* (IVI = 80.59) was found to be the most dominant woody species, followed by *Pinus roxburghii* (IVI = 49.26), whereas *Aesandrabutyracea* had the lowest IVI (2.51) (Table 2).

Table 2.Woody speciesIVIand carbon stock (ton/ha) in the studied forests.

Species	Bajrabarahi SG		MhepiSG		SwayambhuSG	
	IVI	Carbon stock	IVI	Carbon stock	IVI	Carbon stock
Aesandrabutyracea	-	-	-	-	2.51	0.24
Albizia sp.	4.87	0.44	-	-	-	-
Alnus nepalensis	15.67	20.20	-	-	-	-
Areca catechu	10.34	6.34	-	-	-	-
Bauhinia variegata	-	-	4.03	0.04	7.06	0.70
*Bambusa*sp.	-	-	12.56	0.34	-	-
Callistemon citrinus	-	-	13.08	4.98	-	-
Castanopsis indica	27.79	28.51	-	-	-	-
Cedrus deodara	-	-	-	-	2.65	0.03
Celtis australis	9.38	0.31	53.90	30.18	7.31	1.05
Choerospondiasaxillaris	28.78	32.49	5.94	3.39	-	-
Cinnamomum camphora	-	-	37.09	9.46	8.54	2.23
Ficus benjamina	-	-	-	-	5.54	0.61
Ficus elastica	-	-	-	-	12.45	6.64
Ficus lacor	-	-	-	-	3.47	1.69
Ficus religiosa	-	-	11.68	8.06	-	-
Grevillea robusta	-	-	47.60	46.46	6.47	6.74
Ilex excelsa	-	-	-	-	3.90	0.38
Jacaranda mimosifolia	-	-	9.58	1.20	-	-
Litseamonopetela	-	-	14.36	0.06	-	-
Micheliachampaca	-	-	-	-	7.09	0.57
Myrica esculenta	9.13	4.36	-	-	-	-
Myrsinecapitellata	21.65	15.79	-	-	23.32	4.70
Neolitseacuipala	80.45	53.67	-	-	-	-
Osmanthus sp.	-	-	-	-	9.59	0.52
Pinus roxburghii	-	-	15.39	21.29	49.26	15.23
Prunus cerasoides	-	-	8.19	4.74	-	-

Pyrus pashia	2.75	0.43	-	-	37.19	7.88
Sapindusmukorossi	-	-	48.01	15.64	8.80	3.42
Schimawallichii	61.86	115.24	-	-	80.59	68.61
Syzygiumcumini	21.57	12.12	-	-	18.56	7.14
Ziziyphusincurva	5.74	1.60	-	-	5.69	1.03
Unidentified 1	-	-	10.12	2.75	-	-
Unidentified 2	-	-	8.46	1.60	-	-

Biomass and carbon stock

The average biomass and carbon stock of allSGs combinedwere 405.03 ton/ha and 190.6 ton/ha, respectively. The average biomass ofBajrabarahiSGwas 620.22±89.55 ton/ha, which was the highest among the three SGs. Similarly, the average carbon stock of BajrabarahiSG was found to be 291.50±42.09 ton/ha, which was also the highest among three SGs (Figure 5). The lowest carbon stock (150.19±43.14 ton/ha) was found in SwayambhuSG. In addition, a significant difference was found in the carbon stock between the forests (p=0.00148).The contributions of different woody species to the carbon stockwere found different (Table 2). In Bajrabarahi SG, *Schimawallichii* (115.24 ton/ha) had the highest carbon stock and in MhepiSG, *Bauhinia variegata*had the lowest (0.03 ton/ha).

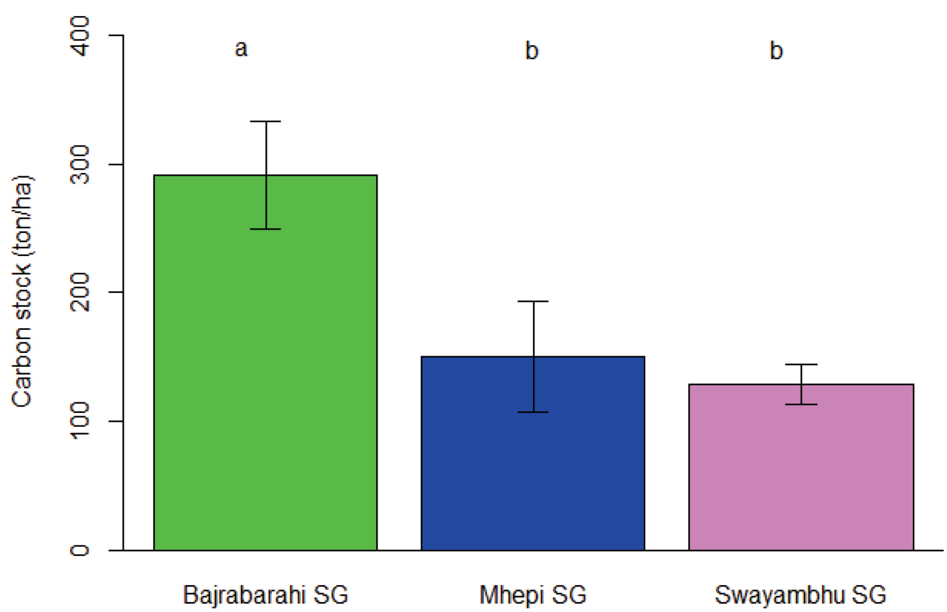


Figure 5. Meancarbon stock in the studied forests; the similar and different lower-case letters on the top of the bars represent,respectively, the non-difference and statistical difference (α = 5%) in mean carbon stock between the studied SGs.

Vegetation Characteristics

Woody density contributes much to the forest structure, functional diversity, ecological processes, and other ecosystem services (Gopalakrishna et al., 2015). The woody species density in the studied SGs ranged from 479 to 502 individuals/ha. The density range obtained in the present study waswithin the range of 318–599 individuals/ha, reported by Sharma et al. (2018) in the Resunga SG, Gulmi, Nepal, but higher than 348 individuals/ha reported for Bajrabarahi SG and less than 601 individuals/ha reported for the Pashupati SG of the Kathmandu Valley (Shrestha et al., 2015). Therefore, the observed density of woody species in the present study can be considered moderate when compared to similar types of SGs in Nepal.

Diameter at breast height and height of the woody specieswere higher in Bajrabarahi SG than in other SGs. In SwayambhuSG,relatively less DBH and height were recorded. This might be due to the new plantation of different woody species in this forest by the forest management group. Likewise, the basal area ranged from 46.87 ± 11.45 to 67.77 ± 7.86 m^2/ha in the present study, which was greater than the basal area of 37.28 m^2/ha for the ChuriaForest in eastern Nepal (Bhuju, 2000) and 34.20 m^2/ha for a disturbed ChuriaForest patch in RupandehiDistrict (Marasini, 2003). In this study, the basal area is lower than the values (79.43–90.64 m^2/ha) reported by Waikhom et al. (2018) in the largest SGs of Manipur, Northeast India. The lower basal area of woody species in these SGs might be due to the dominance of relatively less matured tree species with smaller-girth.

More numberof species were recorded in SwayambhuSG than in Mhepi and Bajrabarahi SGs. Also, SwayambhuSG hada high diversity index,suggesting diverse vegetation with relatively low evenness in this SGcompared to the other SGs.In Swayambhu SG, the dominant woody species were*Schimawallichii, Neolitseacuipala, Grevillea robusta,*and*Celtis australis* as depicted by the IVI analysis. The IVI of a speciesprovidesan idea about the importance of the species in the given ecosystem. It helps to understand the dominance and ecological significance of the species.

Biomass and carbon stock

The vegetation biomass of any forest depends on several factors, such as density, diameter, basal area, height, and age distributionof plants (Lal, 2005). The mean biomass in the three SGs ranged from 275.33±33.19 to 620.22±89.55 ton/ha,which was higher thanthat in the community-managed Hill Sal Forest (120 ton/ha) in Central Nepal (Shrestha et al., 2015), and the tropical riverine forest (178.83 ton/ha) (Baral et al., 2010). The high woody speciesbiomass obtained in the present study might be because ofless disturbances in SGs due to their religious values, compared to other forest types, where the consumption of forest products and active forest management practices might be prevalent.

The mean carbon stock of BajrabarahiSG was found to be highest (291.50±42.09 ton/

ha), followed by MhepiSG (150.19±43.14 ton/ha). The least carbon stock was recorded in SwayambhuSG (129.40±15.60 ton/ha). This was due to the low basal area, DBH, and height of woody species in SwayambhuSG. The old-growth mature forest with larger girth sizes and taller woody specieshas larger carbon pools (Luyssaert et al., 2008). The values of carbon stock obtained in the present study were higher than the Resunga SG, Gulmi, Nepal (127.75 ton/ha) (Shrestha et al., 2018) and in different forest types of Nepal (34.30–98.86 ton/ha) (Baral et al., 2010), and the plantation forest of the Kathmandu Valley (108 ton/ha) (Bhatta et al., 2018). Protected SGs, have been reported to have notably higher carbon sequestration rates compared to other forest ecosystems(Vikrant et al., 2019). However, carbon stock in the SGs studied in this work was lower than the range (481.4–565.2 ton/ha) reported by Waikhom et al. (2018) in the largest SG of Manipur, Northeast India. The difference found in the carbon stocks among these studies might be due to differences in the physiographic regions and vegetation assemblages.

In terms of species contribution on forest carbon stock, the present study revealed that*Grevillea robusta*was the most (31%) contributing species in terms of forest carbon stock in Mhepi SG. Likewise, *Schimawallichii* was the major species with 53% and 40% contributions to the total forest carbon stock in Swayambhu and Baharabarahi SGs, respectively. A similar study conductedin BajrabarahiSGby Nepali et al. (2015) also found *Schimawallichii*as a major species in terms of its contribution to the forest carbon stock(429.5 ton/ha), which was similar to the finding of the present study.

Conclusion

Vegetation characteristics and carbon stocks of three studied SGs, namely Mhepi, Bajrabarahi, and Swayambhu,located inthe Kathmandu Valley revealed 37 species.The amount of carbon stock varied among the three SGs,which might be due to the variation in woody species composition, density, basal area, height, and wood density. Among the species, *Schimawallichii, Neolitseacuipala, Grevillea robusta,*and*Celtis australis* were the common woody species found in these SGs.Moreover, among the species *Schimawallichii*was the mostdominant and ecologically significant woody species.The results of the present study suggest that SGs have supported the preservation of the vegetation assemblage and diversity in the Kathmandu Valley along with other ecological and cultural significances. This indicates the worth of conserving sacred groves and demands detail studies for understanding the eco-economic and cultural significances of those forests.

Acknowledgements

The authors would like to acknowledge the Department of Environmental Science, Amrit Campus, for providing the necessary equipment for carrying out the field study. The authors are also indebted to the Management Committee of Bajrabarahi, Swayambhu, and Mhepi forests for providing permission to conduct this research work.

References

- ANSAB, FECOFUN, ICIMOD,& NORAD (2010). *Forest Carbon Stock Measurement. Guidelines for Measuring Carbon Stocks in Community-managed Forests.* Kathmandu, Nepal.
- Baral, S., Malla, R., & Ranabhat, S. (2010). Above-ground carbon stock assessment in different forest types of Nepal. *Banko Janakari*, 19(2), 10–14.
- Bhatta, S. P., Sharma, K. P., & Balami, S. (2018). Variation in carbon storage among tree species in the planted forest of Kathmandu, Central Nepal. *Current Science,* 115(2), 274–282.
- Bhattarai, K. R., & Baral, S. R. (2004). Potential role of sacred grove of Lumbini in biodiversity conservation in Nepal.Banko Jankari, 18(1), 25–31.
- Bhuju, D. (2000). Floristic composition, Forest structure and regeneration of Churia forest, Eastern Nepal and patch implications in the maintenenance of species richness in an isolated forest site.*Biological Conservation*. 98: 117-125.
- Brown, S. L., & Schroeder, P. E. (1999). Spatial patterns of aboveground production and mortality of woody biomass for eastern U.S. forests. *Ecological Applications*, 9(3), 968–980.
- Brown, S., Sathaye, J., Cannell, M., & Kauppi, P. E. (1996). Mitigation of carbon emissions to the atmosphere by forest management. *Commonwealth Forestry Review*, 75(Janaury), 80–91.
- Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J. P., Nelson, B. W., Ogawa, H., Puig, H., Riéra, B., & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, 145(1), 87–99.
- Devkota, M. P. (2014). Sacred Groves as Sanctuaries for Mistletoe Conservation in Kathmandu Valley Sacred Groves as Sanctuaries for Mistletoe Conservation in Kathmandu Valley. *Springer*. https://doi.org/10.1007/978-1-4614-7161-5
- DFRS. (2018). Forest Cover Maps of Local Levels (753) of Nepal Department of Forest Research and Survey, Government of Nepal.
- FRA. (2020). The Global Forest Resources assessments Report, Nepal (Issue July). Forest Reesarch and Survey, Government of Nepal.

- Gopalakrishna, P. S., Leckson Kaonga, M., Kalegowda Somashekar, R., Satyanarayana Suresh, H., & Suresh, R. (2015). Tree diversity in the tropical dry forest of Bannerghatta National Park in Eastern Ghats, Southern India. *European Journal of Ecology*, 1(2), 12–27.

- Khumbongmayum, A., Khan, M. L., & Tripathi, R. S. (2006). Biodiversity conservation in sacred groves of Manipur, northeast India: Population structure and regeneration status of woody species. *Biodiversity and Conservation*, 15(8), 2439–2456.

- Lal, R. (2005). Forest soils and carbon sequestration. *Forest Ecology and Management,* 220(1–3), 242–258. https://doi.org/10.1016/j.foreco.2005.08.015

- Luyssaert, S., Schulze, E. D., Börner, A., Knohl, A., Hessenmöller, D., Law, B. E., Ciais, P., & Grace, J. (2008). Old-growth forests as global carbon sinks. *Nature*, 455(7210), 213–215. https://doi.org/10.1038/nature07276.

- Lynch, L., Kokou, K., & Todd, S. (2018). Comparison of the Ecological Value of Sacred and Nonsacred Community Forests in Kaboli, Togo. *Tropical Conservation Science*, 11. https://doi.org/10.1177/1940082918758273.

- MacDicken, K. G. (1997). A guide to monitoring carbon storage in forestry and agroforestry projects. Forest Carbon Monitoring Program, *Winrock International,* Institute for Agricultural Development.

- Marasini, S. (2003). V*egetation analysis of Churia forest in Rupandehi, Nepal*. M.Sc. Thesis, Central Department of Botany, Institute of Science and Technology, Tribhuvan University, Kathmandu.

- Nepali, K. B., Pandey, B., & Timilsina, A. (2015). Carbon stock assessment in Bajrabarahi religious forest of Lalitpur District. *Bulletin of Department of Plant Resources,*37(37),92–96.

- Newton, A. C. (2007). Forest ecology and conservation. Oxford University Press,New York

- Pala, N. A., Negi, A. K., Gokhale, Y., Aziem, S., Vikrant, K. K., & Todaria, N. P. (2013). Carbon stock estimation for tree species of Sem Mukhem sacred forest in Garhwal Himalaya, India. *Journal of Forestry Research*, 24(3), 457–460. https://doi.org/10.1007/s11676-013-0341-1

- Pokharel, A.K. & Hallett, J. (2015). Distribution of rainfall intensity during the summer monsoon season over Kathmandu, Nepal. Weather. https://doi.org/10.1002/wea.2544.

- R Core Team (2016). R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria
- Saikia, A. (2006). The Hand of God: Delineating sacred groves and their conservation status in India's far east.*11th Biennial CONFERENCE of the International Association for the Study of Common Property, Bali, 19-23 June 2006. 1–10.*
- Sharma, B. K., Pokharel, C. P., & Shrestha, L. (2018). Forest Diversity and Carbon Sequestration In Resunga Sacred Grove, Gulmi, Nepal. *Journal of Natural History Museum*, 29, 60–69.
- Sharma, E. R.& T. Pukkala. (1990). Volume equations and biomass prediction of forest trees in Nepal. Forest Survey and Statistics Division, MFSC. 85 pp
- Sharma, S., Tiwari, A., Sheikh, M. A., & Kumar, B. (2019). Carbon stock in Kaner Jhir sacred grove and non-sacred grove of India. *Journal of Emrging Technologies and Innovative research*, 6(3), 598–605.
- Shrestha, L. J., Devkota, M. P., & Sharma, B. K. (2016a). Are Sacred Groves of Kathmandu Valley Efficient in Sequestering Carbon? *Journal of Botany*, 2016(3).
- Shrestha, L., Devkota, M., & Sharma, B. (2015). Phyto-sociological Assessment of Sacred Groves in Kathmandu, Nepal. *International Journal of Plant & Soil Science*, 4(5), 437–444.
- Shrestha, L.J., Devkota, M. P., & Sharma, B. K. (2016b). Tree regeneration in sacred groves of Kathmandu valley, Nepal. Ecoprint: *An International Journal of Ecology,* 22, 29–38.
- Vikrant, K. K., Pala, N. A., Negi, A. K., Y.Gokhale, & Todaria, N. P. (2019). Carbon storage in sacred groves- A Study from Chanderbadni sacred grove in Journal of Biodiversity and Ecological Sciences Carbon storage in sacred groves- A Study from Chanderbadni sacred grove in Garhwal Himalaya, Uttarakhand, India. *Journal of Biodiversity and Ecological Sciences*, 3(2).
- Waikhom, A. C., Nath, A. J., & Yadava, P. S. (2018). Aboveground biomass and carbon stock in the largest sacred grove of Manipur, Northeast India. *Journal of Forestry Research*, 29(2), 425–428.

Ornithological Survey and Habitat Quality Study in Rara Lake, Nepal

Mohan Bikram Shrestha[1]*, Kriti Nepal[1], Tek Bahadur Gharti Magar[2], Deepak Rijal[3]
[1]Bird Conservation Nepal, Kathmandu
[2]Independent bird researcher
[3]USAID Paani Project
*Corresponding email: shrmohan5@gmail.com

Abstract

Rara Lake is situated in mountain ecoregion serves as staging post for the long range migratory wetland birds. The lake ambient forest bears the restricted range and globally threatened species.Bird species in the park is reported as unrecorded while habitat quality of the Rara lake providing the refuge to migratory and native bird species is degrading. Adherence to the statement, study was carried to gather the descriptive and evidence-based information on bird species and habitat quality was carried to understand bird status, its activities and habitat quality. Bird count was carried through line transect. Bird behavior, activities, stay-length and lake riparian habitat was noted through direct sighting. Water quality was assessed following American Public Health Association water quality test guideline. The study counted a total of 2415 bird individuals from listed 104 species including 16 migratory Waterfowls, 13 wetland dependent birds and 75 forest birds. The observed bird species ranged from frequent to very uncommon winter visitor stop in Rara lake primarily for fueling during migration. Observed that most of time birds wereforaging at shallow water but merely outside lakes. Discarded trashes in the roosting and foraging site and around the lake circuit trail triggering threats to waterfowls and aquatic biodiversity while higher human movement through the trail causing disturbance to waterfowl. Water quality assessment revealed that Phosphorous and ammonia concentration in Rara lakewere higher than therecommended level for freshwater/aquatic ecosystem connoting lake in the process of eutrophication and acute ammonia toxicity affecting aquatic life. Regular assessment of water quality is required preventing aquatic life from detrimental effects .Contineous monitoring to study their migratory behavior and habitat qualities would be essential to inform conservation policies also linking with eco-tourism activities

Keywords: *Wetland, Birds, Water Quality, Eutrophication, Trashes*

Introduction

Rara lake is a high altitude wetland located in the Rara National Park of Nepal. It is the largest and deepest lake in Nepal (Okino & Satoh, 1986). It is home tothree endemic fish species (Terashima, 1984) and one endemic frog species (Dubios & Matsui, 1983). It inhabits several globally threatened; restricted-ranged; and biome-restricted bird species. Hence, Lake Rara was listed as Ramsar sites –a wetland of global importance in 2007 (Ramsar, 2007) and designated as an Important Bird Areas (IBA) in 2005 (Birdlife International, 2020). A total of 235 bird species was recorded in 2005 (Giri, 2005) whereas 284 in 2015 (BCN& DNPWC, 2015) and additional 6 species totaling 290 (Chaudhary, 2015 unpublished), but bird species in park is still under recorded (Birdlife International, 2020). Rara lake is alsovaluable staging post for migrating wetland birds. Around 40 species have been recorded so far (Birdlife International, 2020).However,understanding of ecosystem dynamics of high altitude wetland is poor (Baral & Bhandari, 2011). While the Rara lake is distant and thus maintained natural beauty, the lake is under threat of human flow, activities and pollutant (Cantonati et al., 2001, Battarbee, 2000; Battarbee et al., 2002a, 2002b;; Galassi et al., 1997; Grabherr et al., 2006; Rupakheti et al., 2017) as well as local pollution from settlements and mountain tourism (Chandan et al., 2008; Harris et al., 2009). High altitude wetlands in Himalayas are breeding areas for several globally threatened and common waterfowls, and staging area for many more (Mishra & Humbert-Droz, 1998). About 67 avifauna included of threatened bird species are reported associated with high altitude wetlands (Baral, 2005, 2007), large-sized high altitude wetland and glaciated broader valley with rivers and streams recorded with thriving population and diversity (Baral & Bhandari, 2011). Mention the importance of good water quality for avifauna, the timely monitoring helps to maintain the pristinely preventing biodiversity extirpation from the local area. This study is carried intending to provide descriptive and evidence-based information onbird species, their behavior and activities, interspecies interaction andthe present habitat conditions.

Materials and Methods

Study Area

Lake Rara located at 29° 24'N and 82° 05'E at an elevation of 2990masl (Ferro, 1978/79) is a Himalayan lake with 9.8 km^2 surface area and maximum water depth of 167m (Ferro, 1978/79; Okino & Satoh, 1986). Lake Rara has a small catchment area of 30 Km^2 with more than 30 brooks flow into the lake (Okino & Satoh, 1986) but only one outlet- Kater Khola (locally called Khatyad khola) (Terashima, 1984; Okino & Satoh, 1986) that flow through a very deep gorge around 7 km downstream and then flows into Karnali River 26 Km westwards of Lake Rara (Terashima, 1984).The lake is surrounded by mountains ranging from 3200 m asl in the south to 3,700-3,900 m asl in the north and south-west forming a wide rhomboid-shaped valley that opens to the east (Yagi et al., 2009). The forest consists of several conifer species. The slopes below 3150 m are predominantly covered by Himalayan Pine (*Pinus wallichiana*) (ICIMOD, 2015). The north-slopes are covered with Himalayan Fir (*Abies spectabilis*)and Himalayan Birch (*Betula utilis*) forest, Rohododendron scrubs and alpine meadows; while the southern slopes have West Himalayan Spruce (*Picea smithiana*) Boiss., Himalayan pine and Brown oak (*Quercus semecarpifolia*) forests (Yasuda & Tabata, 1988). The lake and its catchment lie within the temperate subalpine climatic zone. The temperature in the Rara was recorded to minimum of -4.3°C and maximum of 16.4°C in 2016 while received an annual precipitation of 833.2 mm in 2017 (DHM, 2018). Limnological information in Nepalese lake is limited and even markedly limited is limnological information of Rara lake. Ferro (1978/79) gathered basic limnological and biological data and defined Rara lake as warm monomitic and oligotrophic. Later Swar (1979) reported cladocera from the lake. Chironomidae larvae, Grammaridae, Diaptomidae, Cydorinae, *Synedra* spp., *Gamphonmea* spp. *Cocconeis* sp. *Cymbella* sp. *Navicula* sp. *Oscillatoria* sp. were macroinvertebrates and macrophytes obtained in diet of fish species in Lake Rara (Terashima, 1984).

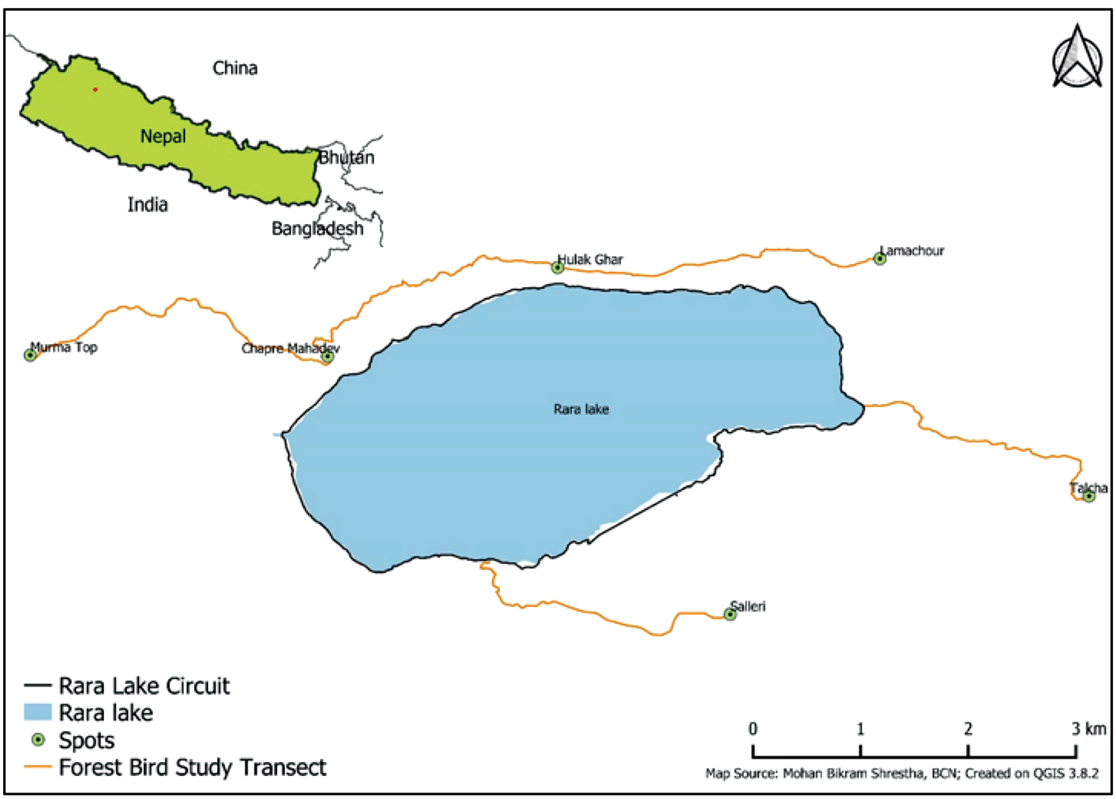


Figure 1: Bird study transect in and around Rara lake

Methods

Bird study

Bird count and Analysis: Thestudy was conducted from 12 December 2019 to 3 January2020 for 23 days. Two different study methods; i) Direct count of waterfowls (for duck, geese and grebe) and wetland dependent birds (for sandpiper, waterhen, moorhen and wagtail) ii) Mackinnon lists for forest birds in the Rara Lake periphery was applied (Bibby et al., 2000). The bird counts were performed during the daytime (0730-1130hrs & 1500-1800hrs). Binoculars (Opticron-10x42 COUNTRYMAN BGA HD WP, Field 6° and Vixon 10x32) and Telescope (AG80) for bird surveyandDigital Cameras (Canon EOS Kiss X80 with 55-250mm Zoom lens, Fujifilm 24-720 and Canon Power Shot SX60HS were used for taking photographs of the observed birds. Waterfowlsand wetland dependent birds were studied walking alongthe Rara lake circuit trail for 15 days while a total of 5 transects for the study of forest birds were carried spending a day in each transect. Transects were set starting from Rara Lake until end in range posts (Rara- Lamachour, Rara-Talcha and Rara-Salleri), used trails in the forest (Chhapre Mahadev-Hulak ghar) and hiking trail (Rara-Murma Top). Trails and transect followed were marked in Geographical Positioning System (Garmin GPS 64s Map). Bird congregation and habitats were noted during bird survey. Bird species identification was done following Helm Field Guide-Birds of Nepal(Grimmette et al., 2016). Scientific nomenclature and systematic positionof birds followedBird Conservation Nepal Checklist-2018 (DNPWC and BCN, 2018).Species diversity (H') and evenness (e) was accounted following Shannon - Weiner diversity index (Shannon and Weaver, 1949).

Bird Activities: Bird activities in and around the lake was noted for the whole day from dawn and dusk through vantage points. Activities such as; roosting, foraging, loafing, swimming, dabbling etc. were noted. Locations around the lake proximity mostly used by birds was recorded. Identified locations were marked in GPS for maps production. Maps were produced through Quantum Geographical Information System (QGIS) version 3.8.2.

Feeding Behavior: The food preference, food choice and locational shifting of water birds were carried through direct observation method/photography/videography. Besides, water bird dispersion, dispersion extent and time were analyzed. Association of several species for food resources and space was noted during the field visit. Bird and/or flock association with the habitat and prey was noted walking throughout the lake area. Different habitat types were noted and the specific location was marked in GPS. The GPS point was extracted and imported in Google earth for delineation of area and map was produced through Quantum Geographical Information System (QGIS) version 3.8.2.

Migratory bird stay-length: Migratory birds and its length of stay staging in the Rara lake was noted during field study. Migration pattern of the birds observed in and around the Rara lake was categorized following the IUCN Red List (IUCN, 2020).The team observed the migratory bird presence/absence in the Rara Lake every morning and afternoon during the study period. The date of their departure was noted.

Habitat Study

Water Quality Assessment: Water sampleswerecollected from five purposively selected locations; one of the Inlet at the extreme north of the lake, Outlet, Marshland vicinity, park office residence and undisturbed lake corner relatively with no human flow (Figure 2). Water quality parameters such as Water temperature (^oC) and transparency measured on site while for rest of water quality parameters, water samples of volume 500ml were collected in sampling bottles. To prevent the changes in Dissolved oxygen content of the collected samples, thesamples were fixed with Manganese sulfate ad Potassium hydroxide on site (reference needed). The collected water samples were stored in an ice box and transported to Nepal Environmental and Scientific Services Pvt. Ltd-(NESS) in Kathmandu for water quality analysis within 48 hours' time. Water quality parameters quantified employing Method described in American Public Health Association (APHA, 1998) (Table 1).

Table 1: Water quality parameters and assessment method

S. N.	Parameters	Test Methods
1.	Water Temperature (^oC)*	Thermometer
2.	Transparency (m) *	Secchi disc
3.	pH @ 15^oC	Electrometric
4.	Electrical Conductivity (µS/cm)	Conductivity Meter
5.	Turbidity, (NTU)	Nephelometric,
6.	Total Alkalinity as write correctly (mg/L)	Titrimetric
7.	Chloride (mg/L)	Argentometric Titration
8.	Dissolved Oxygen (mg/L)	Winkler Azide Modification (Dilution & Seeding
9.	Free Carbon Dioxide (mg/L)	Titrimetric
10.	Total Nitrogen (mg/L)	Macro Kjeldahl
11.	Ammoniacal - N (mg/L)	Direct Nesslerization
12.	Total Phosphate (mg/L)	Ascorbic Acid

**Examined in field*

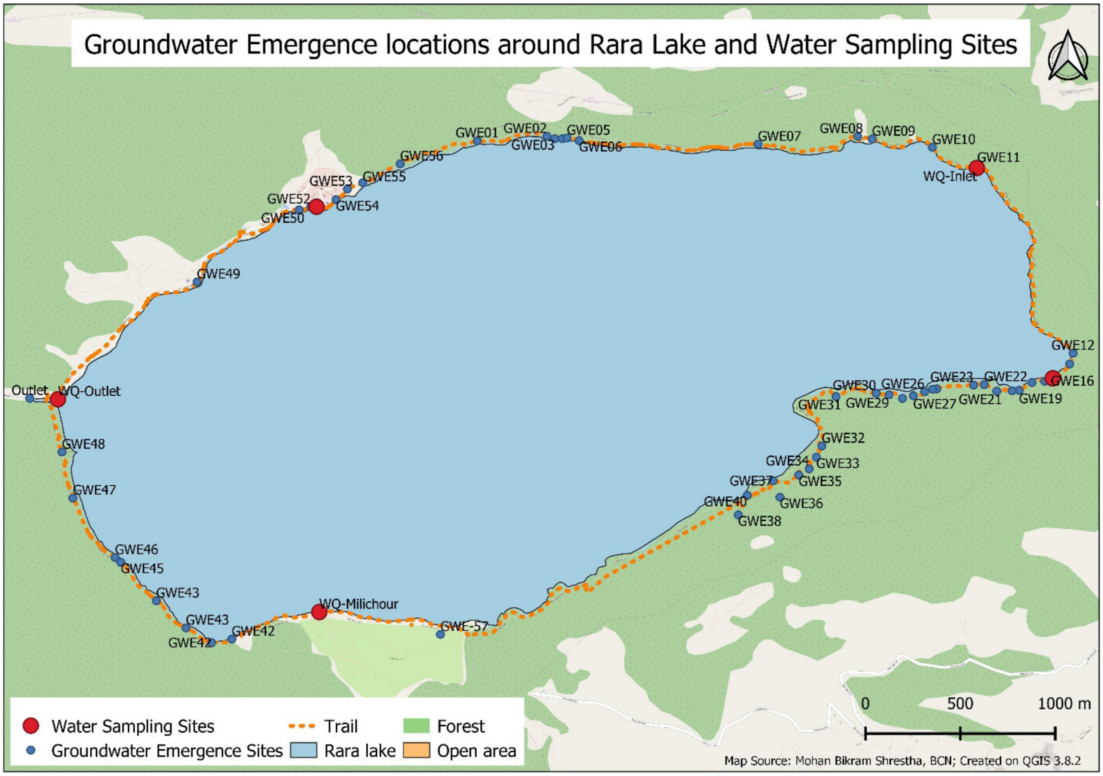
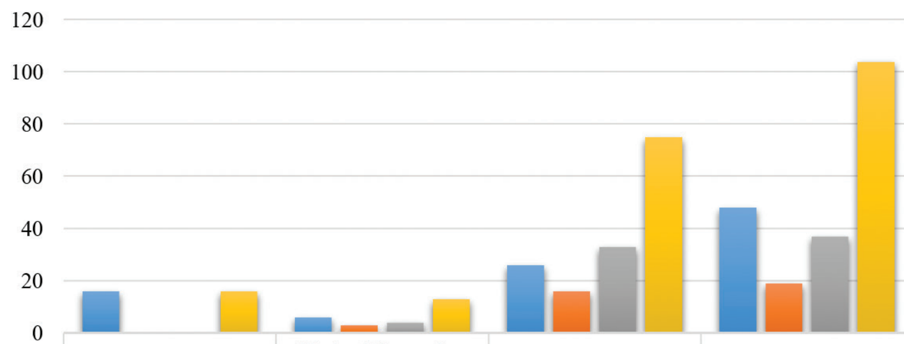


Figure 2: Water sample collection sites around the Rara lake

Assessment of Lake ripariancondition: Lake riparian habitat was assessed based onfood availability and foraging area; Habitat condition(such as damp soil and puddles); Roosting sites (fallen trees, logs, sandy banks and marshland); Nesting sites;Congregation sites; time spent in particular site; activities (demarcating the most preferential habitat in and around the lake)and solid waste disposal at the lake proximity.Discarded non-degradable trashes by the visitors around the lake proximity was thoroughly examined in whole lake circuit to know the kinds/types while collection of trash in 1 kilometer stretch in the trail in circuit was collected to quantified amount.Existing sewage disposal mechanism from the nearby hotels, park office and residence quarters and park security army post was carried. Total number of toilets in the hotels, army camp and National Park Office and park staff quarters was counted and distance between septic tank and Rara Lake was measured

Results and Discussion

The study accounted 104 bird species (Annex:1) and counted 2415 individuals belonging to 15 Orders and 39 Families. Of the total 104 species, 16 were counted as Waterfowls, 13 Wetland dependent and 75 were Forest birds. Among the recorded species 67 species shows some sort of migration. This included48 full migrants and 19 altitudinal migrants) whereas 37 bird species are non-migrant. The full migrants included of all 16 waterfowl species, 6 species of wetland dependent birds and 26 species of forest birds; while altitudinal migrants included of 3 species of wetland dependent birds and 16 species of forest birds. The majority of non-migrants are forest birds (33 species) (Figure 3).Of the total 2415 bird individuals counted, Common Coot (*Fulicia atra*) accounted for the highest count (489) followed by Plain Mountain Finch (*Leucosticte nemoricola*) (420).



	Waterfowls	Wetland Dependent Birds	Forest Birds	Total
Full Migrant	16	6	26	48
Altitudinal Migrant	0	3	16	19
Non-Migrant	0	4	33	37
Total	16	13	75	104

labels missing on axes!

Figure 3: Migrant and non-migrant bird species observed in and around Rara lake

Rara lake have been serving as stopover site, primarily as fueling ground during the migration for the winter migratory waterfowls. Bar-headed Goose (*Anser indicus*), Gadwall (*Anas stepera*), Mallard (*Anas platyrhynchos*), Red-crested Pochard (*Netta rufina*), Common Pochard (*Aythya ferina*), Tufted Duck (*Aythya fuligula*) are common winter visitors and passage migrants making stopover in Rara lake during the migration while Greylag Goose (*Anser anser*) is very uncommon passage migrant and rare winter visitor observed in the Rara lake. Similarly, Lesser Black-headed Gull (*Larus heuglini*) and Brown-headed Gull (*Chroicecephalus brunnicephalus*) is a rare passage migrant visit in winter season. While, Pallas's Gull (*Ichthyaetus ichthyaetus*), Goosander (*Mergus merganser*), Great Creasted Grebe (*Podiceps cristatus*), Great Cormorant, (*Phalacrocorax carbo*), Common Moorhen (*Gallinula chloropus*) and Common Coot (*Fulica atra*) are common and frequent winter visitors. Black-necked Grebe (*Podiceps nigricollis*) is localized scarce winter visitor (Grimmett et al, 2016; IUCN, 2020). Rara is evident to be the stop over primarily as fueling ground to the observed waterfowls. The recorded waterfowls congregate in Rara Lake as wintering ground or stopover observing the stay length of waterfowl.The number of waterfowls and wetland dependent birds during study time (winter season) were observed comparatively lower than those of the forest birds. Diverse forest bird species (75) were observed in the lake proximity. The bird diversity in and around Rara lake proximity is highly diverse (H'-3.364) and bird species almost equally distributed (e-0.724). Despite diverse forest bird encounter rate, asymptotetype curve was obtained for forest bird implying the need of accounting theunder recorded forest birds (Figure 4).

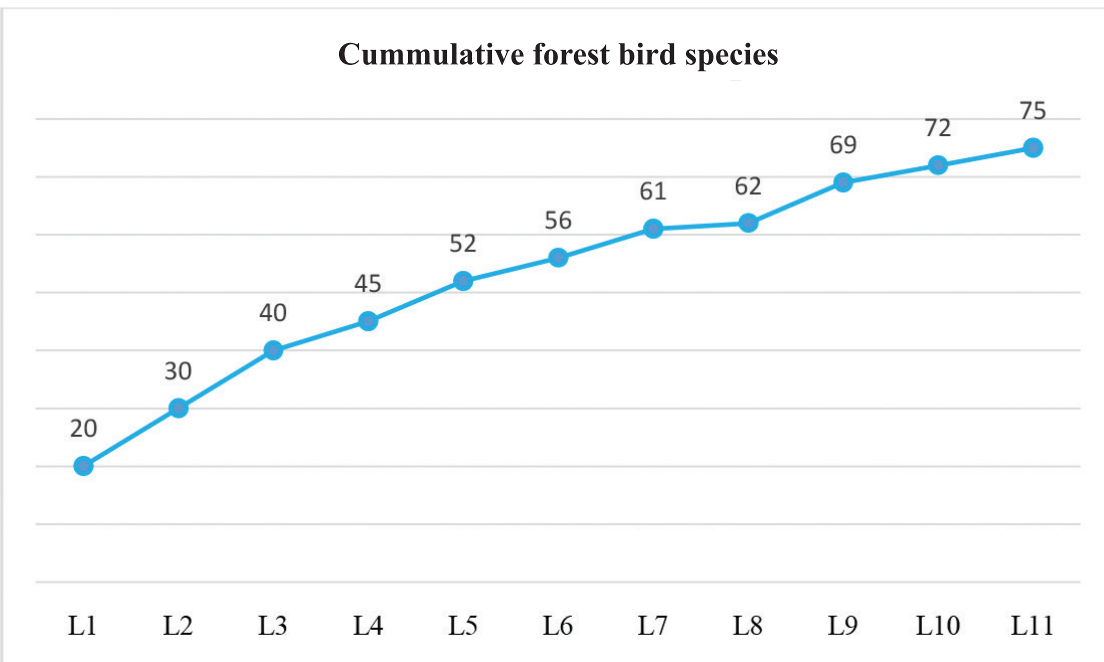


Figure 4: Species richness curve for forest birds

A total of 284 bird species were recorded from Rara National Park and its surrounding area (BCN & DNPWC, 2015) and 6 new species for the National Park was recorded with total of 290 species by Chaudhary et al. in 2015. In this study, 6 more species were observed. These are Mountain scops-owl (*Otus spilocephalus*), White-tailed sea-eagle (*Haliaeetus albicilla*), Peregrine falcon (*Falco peregrinus*), Green shrike-babbler (*Pteruthius xanthochlorus*), Barn swallow (*Hirundo rustica*) and Tree pipit (*Anthus trivialis*).The revised and updated checklist of bird of Rara National Park and its bufferzone area with 296 bird species was published in 2020 (BCN & DNPWC, 2020).

Birds were active and feeding during the morning hours and in the late afternoon. Within birds, Eurasian Coot makes morning call between 0540-0615hrs. Generally, birds are active in dawn and dusk foraging and singing (forest birds). However, bird activities varied from species to species and with the season-winter season and breeding season. The winter season bird activity study found waterfowls spending majority of time foraging, revitalizing protein content for migration. Eurasian Coot, Black-necked Grebe, Tufted Duck, Gadwall, Common Pochard and Red-crested Pochard observed active and feeding closer to the lake bank. These waterfowls found feeding on floating weeds or dive under water to collect submerged weeds. Great crested grebe was observed solitary, and occasionally observed in flock (up to 22 individuals). Great crested grebe was observed highly sensitive human disturbance and does not appear closer to the lake bank. Often occasionally appear to human disturbance closer at the bank, it dives underwater and move away to safer places. It is observed swimming and feeding on fish. Likewise, Gulls were observed staying away from human disturbances like Great crested grebe. Gulls were noted soaring above the lake in the afternoon. Mostly gulls are seen messing with Eurasian coot and confiscating fish feeding by Eurasian coot. Gulls are highly active during windy weather causing wave on the lake. The wave in the lake bring dead fishes drifting. Similarly, Mallard, Goosander, Greylag Goose, Bar-headed Goose and Gadwall are the most sensitive to human disturbances. These birds observed loitering on land or observed roosting and pruning on fallen dead trees.Much perimeter of Rara lake (15Km) is surrounded by Pine-Rhododendron mixed forest with marshland and sandy deposit in scattered patches, boulders (at Eastern bank) and park office, lodges and Army camp (at Northern Bank). These waterfowls were noted loafing, roosting and foraging in marshland while common Pochard were roosting at sand deposited bank. Common Coots, Great Cormorant and mallard were roosting on the fallen tree/stump. Lake riparian is providing nice space for various activities. However, discarded trashes were observed in the roosting and foraging site. In addition, Rara lake circuit trail is closed the riparian habitat with continual human passerby. Upon disturbance (human movement), it escapes away to safe distance and get back to same spot (Figure 5).

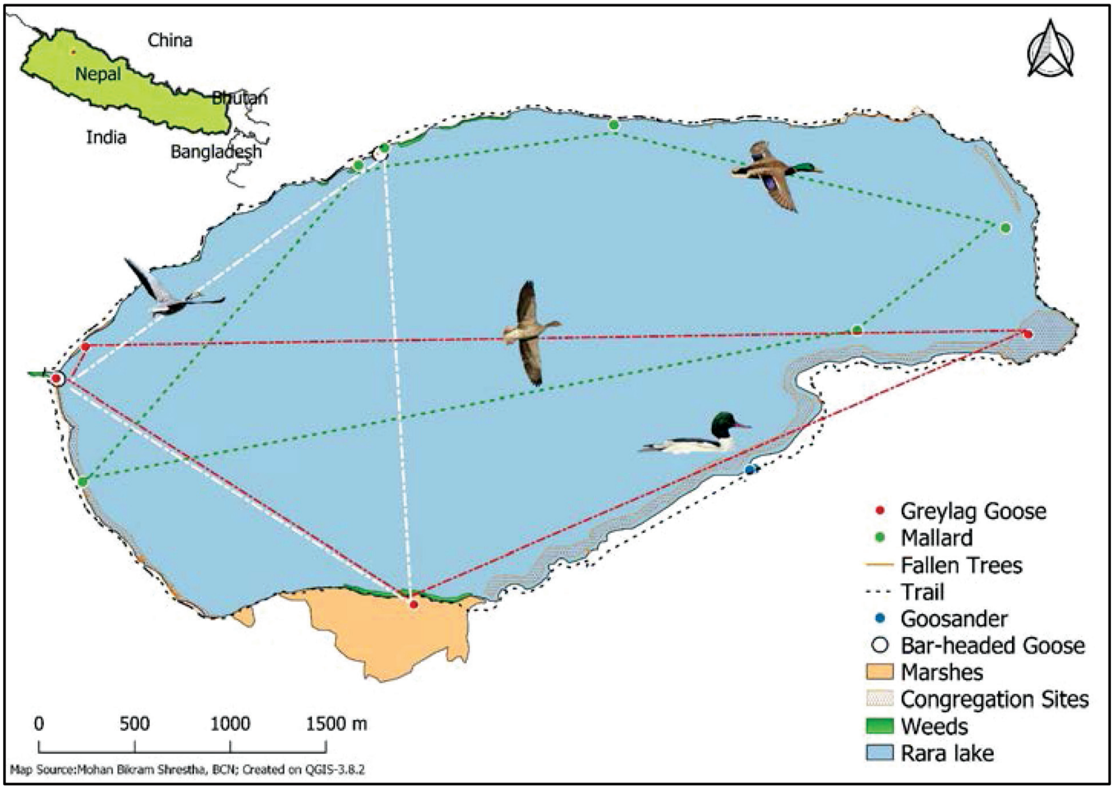


Figure 5: Waterfowls (Greylag goose, Mallard, Bar-headed goose and Goosander) movement in Rara lake periphery

Larger part of littoral zoneof the Rara Lake is highly productive with floating aquatic weed, emergent reeds and submerged algae . Hence, waterfowls are observed congregated the shallow water zone, shallow water marshes, marshland and sand banks. The depth of Rara Lake at the middle is higher where waterfowls entirely depending on fishes such as Great Crested Grebe and Gulls. On windy afternoon, majority of waterfowls are found shifting the location toward wind direction in Northeastern bank (Dufechour – Thakurnath). Primarily, carnivore waterfowls (Gulls, Cormorant) were observed feeding on the fish, while omnivore waterfowls such as Common Coot and Black-necked Grebe were found foraging on aquatic weed and fish upon availability. Dabbling Ducks such as Gadwall, Mallard, Bar-headed Goose and Graylag goose were observed foraging on aquatic insects, mollusks and insects found in the marshland. Similarly, Common Moorhen was observed feeding on aquatic insects. Breeding/foraging places outside lakes is not found. The waterfowls observed in the lake are more confined within the lake proximity. However, forest birds such as Snow Pigeon and Bearded vulture was observed away from Rara lake periphery to Murma village locating at the West of Rara

Lake. Waterfowls were observed confined to Rara lake proximity. No such alternative habitat found or delineated besides Rara lake periphery during this winter season survey. However, it is wetland dependent birds use multiple habitats since majority of wetland dependent birds are altitudinal migrants and anticipated these birds could be foraging in nearby farmland in Lamachour-Gamgadi area (Figure 6).

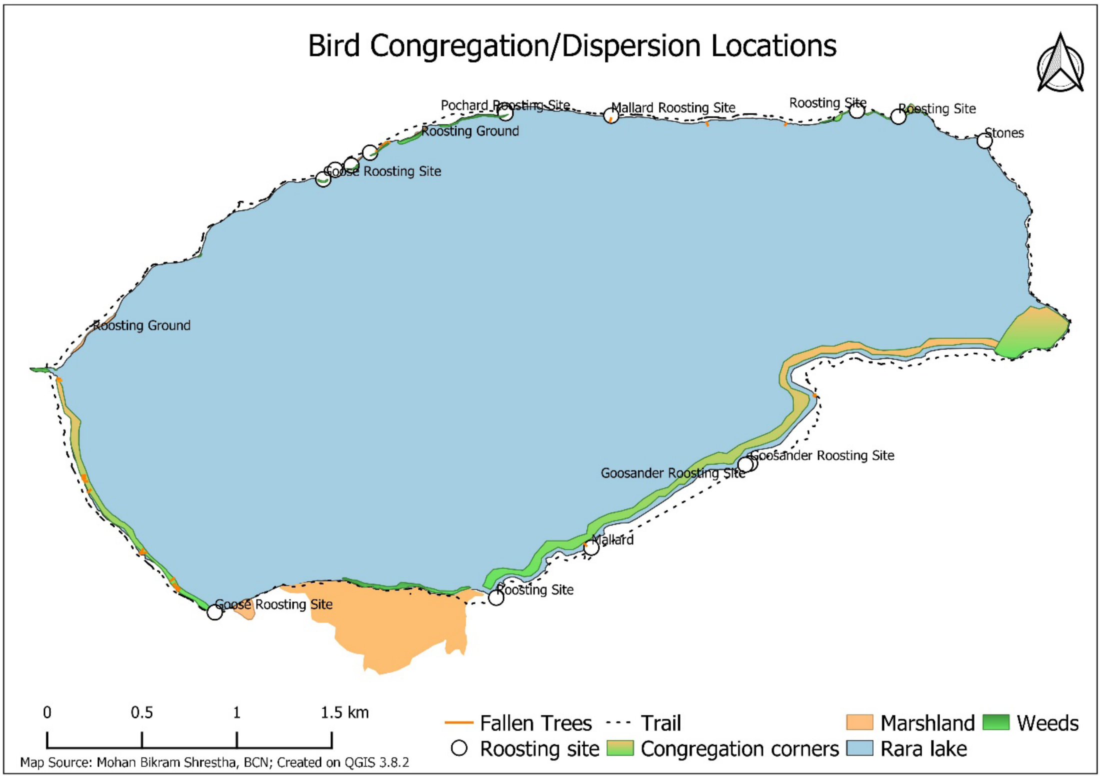


Figure 6: Bird congregation and roosting and dispersion location in Rara Lake

The length of stay of the majority of observed migratory birds could not be ascertained since waterfowls was seen during whole field study tenure. However, departure date of Bar-headed Goose was noted. Bar-headed Goose were observed for 9 days (12-20 December, 2019) in Rara lake. Among waterfowls, Bar-headed goose was not noted while only 4 individuals of Goosander were counted in later count. Waterfowls migration is related with day length, lower temperatures, changes in food supplies and genetic predisposition.The foraging ground of Bar-headed Goose was covered by snowfall hence have migrated from the Rara lake in search of preferred habitat. For further understanding of migration goose required the application of advance scientific tools such as banding, satellite tracking or geo-locator. This will locate other migration stopover/wintering locations for protection of birds and saving the habitat.

The surface water temperature of Rara Lake ranged between minimum of 11°C to maximum of 13°C during the water sample collection. Travelling from one site to another took time hence water collection time was different, thus the temperature was obtained different. Transparency of water in Rara Lake ranged from 12.6-16.3m with an average of 14.28.The water quality test result (for the winter season) are; average pH at 15°C-7.90 ±0.23; Turbidity <1-3 NTU; Total alkalinity range (mg/l) 129.20±2.68; Residual Chloride (mg/l) 3.17±0.83; Dissolved oxygen (mg/l) 7.67±0.58or 101±8.41% saturation considering conversion factors temperature (11°C and 12°C) and elevation (2990m); Free Carbon dioxide (mg/l) 15.92±8.06; Total Nitrogen range (mg/l) 8.01±2.27; Ammonia content (mg/l) 0.06±0.03 and Total Phosphate range (mg/l) 1.01±2.23. Detailed water quality analysis results are present in table 2.

Table 2: Water quality analysis results of Rara Lake (4January, 2020)

S. N	Water Quality Test Parameters	Site-wise Observed Values					Min	Max	Mean ± SD
		GH	MC	OL	DC	TN			
1	Water Temperature (°C)	12	11	11	13	13	11	13	12.00±1.00
2	pH @ 15°C	7.6	8.1	8.1	7.7	8	7.6	8.1	7.90 ±0.23
3	Electrical Conductivity (µS/cm)	183	187	184	196	182	182	196	186.40±5.68
4	Turbidity (NTU)	3	<1	1	2	2	1	3	2.00±1.14
5	Total Alkalinity as CaCO3, (mg/L)	128	128	134	128	128	128	134	129.20±2.68
6	Residual Chloride (mg/L)	3.97	4	2.97	1.98	2.97	1.98	3.97	3.17±0.83
7	Dissolved Oxygen (mg/L)	8	7	8	-	-	7	8	7.67±0.58
	Dissolved Oxygen (% saturation)*	108*	92*	105.3*	-	-	92*	108*	101±8.41*
8	Free Carbon Dioxide (mg/L)	12.6	8.4	16.75	29.3	12.6	8.37	29.3	15.92±8.06
9	Total Nitrogen (mg/L)	11.9	7.4	7.41	7.41	5.92	5.92	11.9	8.01±2.27
10	Ammonia (mg/L)	0.06	0	0.05	0.11	0.06	0.04	0.11	0.06±0.03
11	Total Phosphate (mg/L)	0.02	0	0.01	5	0.03	0.01	5	1.01±2.23

GH-Gulma Headquarter; **MC**-Milichour; **OL**-Outlet; **DC**-Duphechour; **TN**-Thakurnath

*Value after Conversion

There are limited studies on water quality analysis of Rara lake. Within available studies, parameters considered in water quality analysis are not uniform and methods applied varied. Water quality test parameters are dependent on the interest of agencies, institutions or involved in water quality research (Sharma et al., 2005). The water quality studies on Rara lake could be obtained from late 1970s. Ferro in 1978/79 gathered limnological and biological data for the first time and measured depth of the Rara Lake as 167m,surface water quality parameters (Transparency, temperature, electrical conductivity and pH and other water quality parameters such as Dissolved Oxygen, Phosphate, Ammonia, Nitrite, Nitrate, Silica and EDTA hardness.Later in 2015/16, Hydrochemical study was conducted by graduate student from Kathmandu University. In 2018, Paani Project from USAID carried water quality test. And the recent in 2019, Bird Conservation Nepal (BCN) conducted a water quality analysis of selected parameters as a part of its Study-Ornithological Survey to understand migratory behavior and threats to bird of Rara Lake.

While comparing water quality test result in this study corresponded with the results obtained by Okino and Satoh (1986) and Gurung et al. (2018) whereas water quality results relatively differed with results obtained by Paani Project carried (2018) with no justified reasons for the results mentioned in the report.

Table 3: State of Water Quality of Rara Lake over time

Water Quality Test Parameters	May 1983*	October 2015**	April 2016**	April 2018***	January 2020
Transparency	15.55	18.9	17.53	-	14.28
Water Temperature (°C)	12.71	18.79 ± 1.7	14.83 ± 1.8	-	12.00±1.00
Electrical Conductivity (µS/cm)	131.28	189.93 ± 5.3	189.22 ± 15.8	-	186.40±5.68
pH	8.53	8.42 ± 0.3	8.32 ± 0.22	6.7[a]	7.90 ±0.23[b]
Turbidity, (NTU)	-	2.43 ± 3.48	1.71 ± 0.86	30	2.00±1.14
Dissolved Oxygen (mg/L)	7.56	6.73 ± 0.6	10.6 ± 1.5	-	7.67±0.58
Dissolved Oxygen (% saturation)	101.71	105.46±9.4	160.31±22.84	-	101±8.41
Total Alkalinity as CaCO3, (mg/L)	-	-	-	241	129.20±2.68
Residual Chloride (mg/L)	-	-	-	-	3.17±0.83
Free Carbon Dioxide, (mg/L)	-	-	-	-	15.92±8.06
Total Nitrogen, (mg/L)	ND	-	-	15.2	8.01±2.27
Ammonia, (mg/L)	ND	-	-	2.02	0.06±0.03
Total Phosphate, (mg/L)	Low	0.0 ± 0.01	0.06 ± 0.01	3.68	1.01±2.23

Water temperature varies with season and day time. Hence, temperature of water observed different. Rara lake proximity will be filled with snow during winter and last till spring. The temperature seems almost similar from January till April. Temperature data of October recorded higher than temperature record of other time with slight change in temperature. The temperature coefficient value (R^2) deviated by 0.06 or 6% implying some temperature fluctuated with season. The future temperature data is predicated to be in between 12°C and 14°C referring to the regression line obtained (Figure 7).

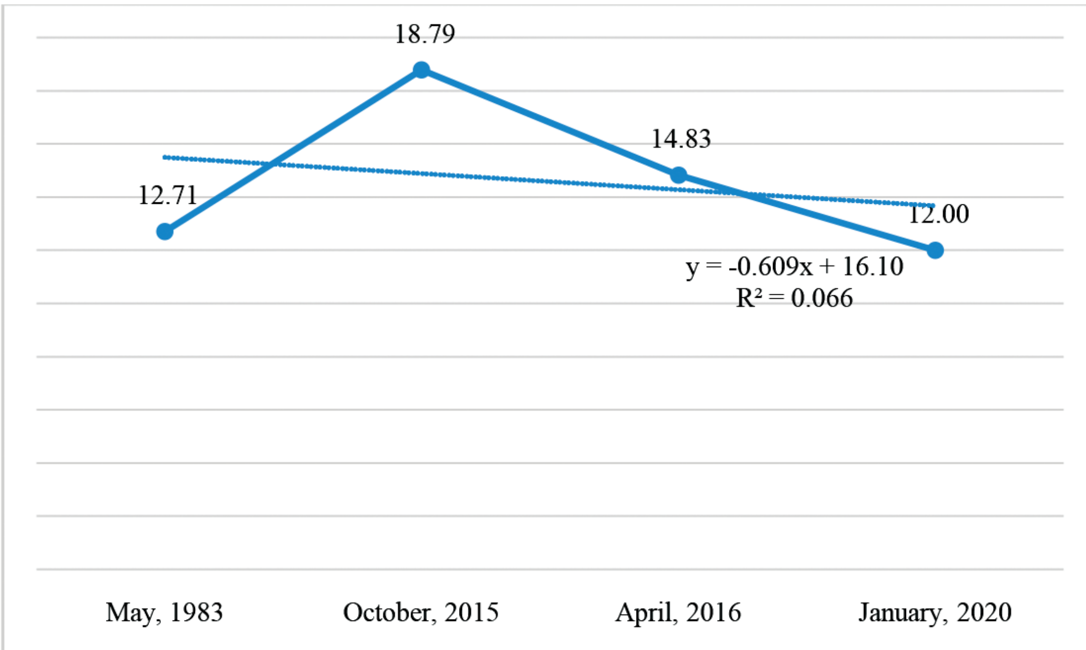


Figure 7: State of water temperature of Rara lake over time (1983-2020)

Transparency of water of Rara lake seems almost equal. The coefficient of determinant of transparency fit to the regression equation by 0.10 or 10 % implying slight change in transparency (Figure 8).

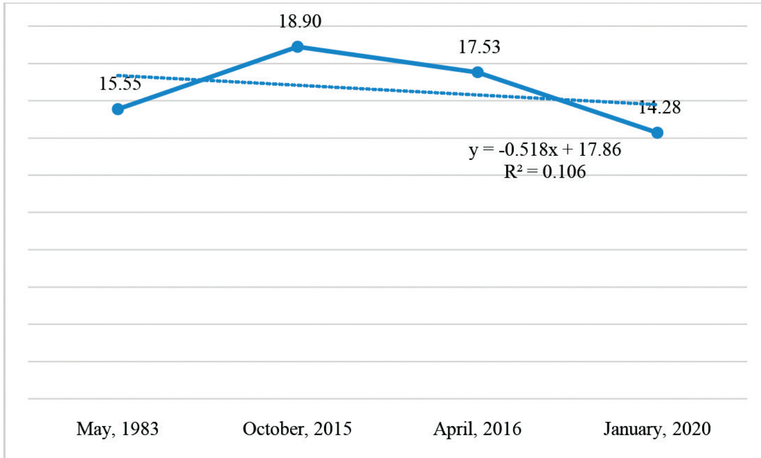


Figure 8: Water transparency of Rara lake over time (1983-2020)

Turbidity besides water quality analysis of April, 2018 are in similar range. Turbidity of water analysis of April is highly deviated from other water quality results (Figure 9). The obtained low coefficient of determinant (R^2) value (0.06 or 6%) clearly implied the test result is unconvincing. Or the water sample must have taken from the shore during windy day. During windy day the water becomes highly turbid at the shoreline due to the wave striking bank with sand and clay.

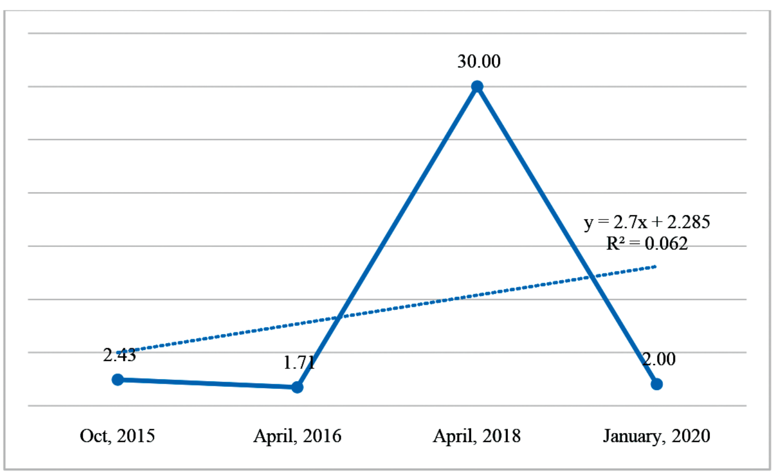


Figure 9: Water turbidity assessment result over time 2015-2020

Electrical conductivity is rising. The electrical conductivity coefficient is increased by 0.55 or 55%. The reason could be the increase in cations and anions in the water (Figure 10).

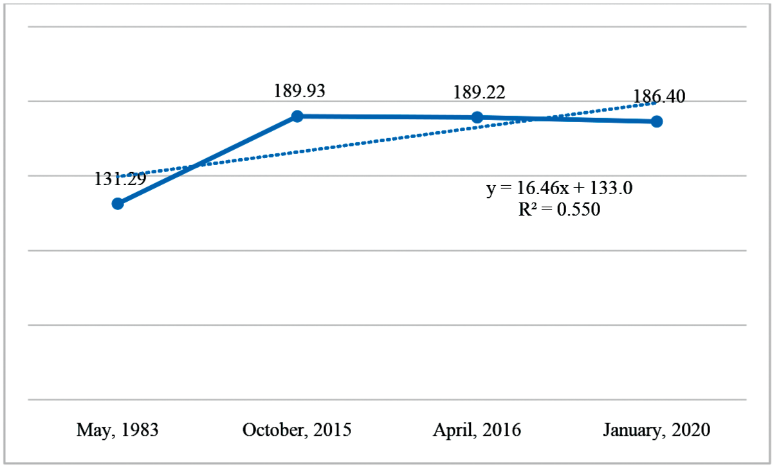


Figure 10: Electrical conductivity test result of water of Rara Lake over time 1983-2020

pH remained almost same range besides April, 2018 test result (Figure 11).

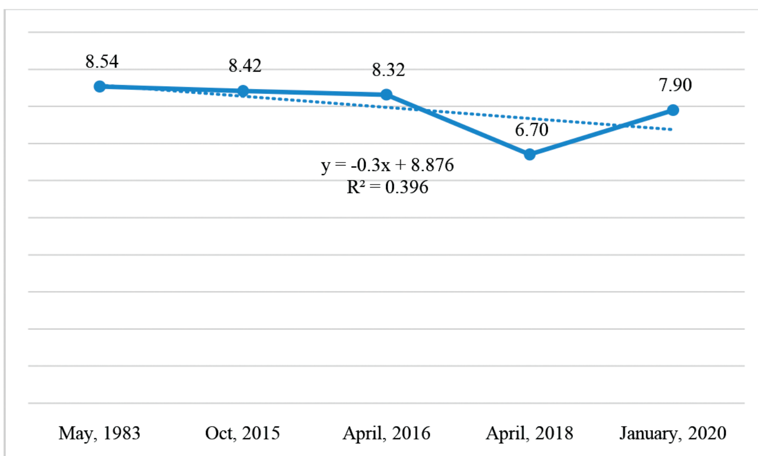


Figure 11: pH result of water of Rara lake over time 1983-2020

Dissolved Oxygen ranged almost similar beside test result of April, 2016. The resulted higher amount of oxygen in April could be of higher photosynthesis rate (Figure 12).

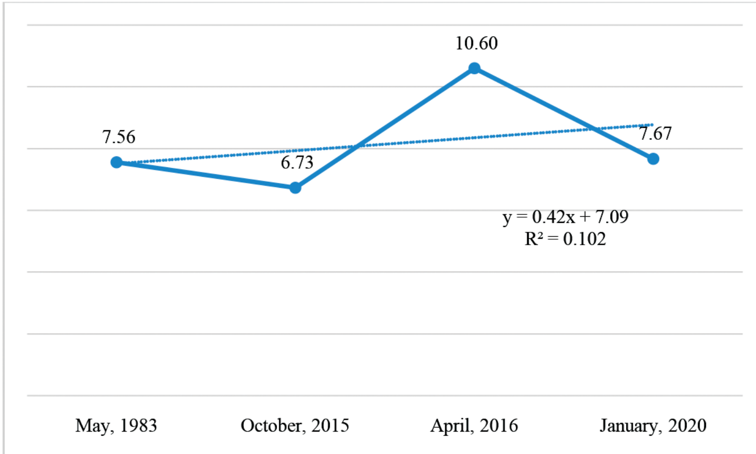


Figure 12: Dissolve oxygen content in water of Rara lake over time 1983-2020

High deviation in total phosphate amount is observed. Phosphate amount is required to be checked and justified by further water quality analysis (Figure 13)

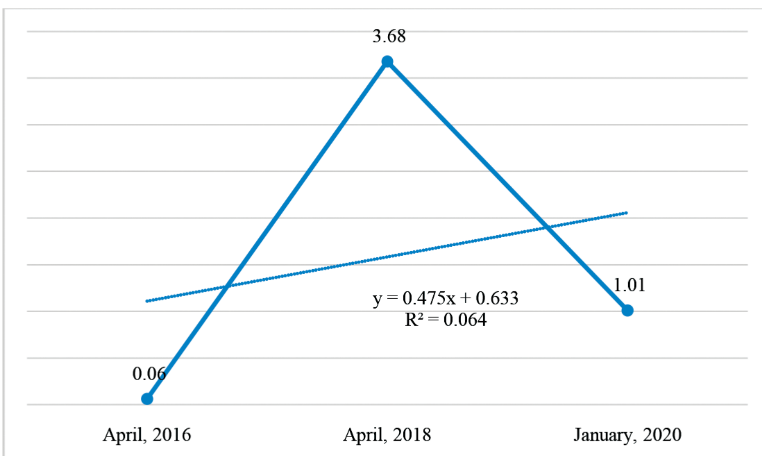


Figure 13: Total Phosphate content in water of Rara lake over time 2016-2020

Total nitrogen amount differed highly. The amount need to be checked and justified by further water quality analysis (Figure 14).

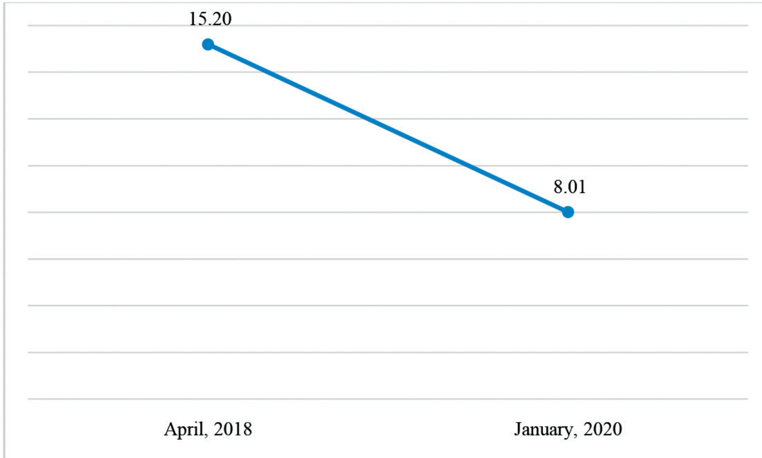


Figure 14: Total Nitrogen content in water of Rara lake over time 2018-2020

Ammonia amount differed highly. The amount need to be checked and justified by further water quality analysis (Figure 15).

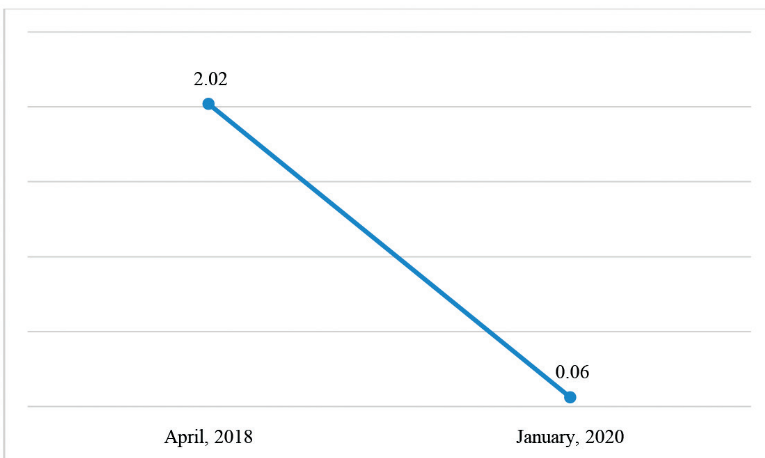


Figure 15: Ammonia content in water of Rara lake over time 2018-2020

Water quality in aquatic ecosystem is dependent on photosynthetic process, physical interactions and biochemical cycles. Additionally, anthropogenic stresses, particularly the introduction of chemicals in water, may adversely affect many species of aquatic flora and fauna that are dependent on both abiotic and biotic conditions. Water quality parameters of concern are traditionally dissolved oxygen (because it may cause fish kills at low concentrations) as well as phosphates, ammonia and nitrate (because they may cause significant changes in community structures if released into aquatic ecosystems in excessive amounts (WHO, 2020). Similarly, Water temperature has significant influence in metabolic rate in fishes, dissolve oxygen and carbon dioxide in water (Kapila et al., 2002). However, an abrupt change in temperature alter the behavior, hematology and serum enzyme activities of the fish. United States Environmental Protection Agency (USEPA) suggested freshwater temperature should be within limit that protect against mortality of important species or site-specific temperature limit that preserves normal species diversity or prevent appearance of nuisance organism (USEPA, 1986). Nepal Water Quality Guideline (NWQG) for the Protection of Aquatic Ecosystem set pH value relative to background suggesting pHvalue of aquatic ecosystem should not be allowed to vary from the range of the background (CBS, 2008). However, pH value of Rara lake water is within the recommended range (6.5-9.0) set by USEPA and Canadian Water Quality Guidelines (CWQG)-Water Quality Standards for Aquatic life and Recreation (CWQG, 2008). NPQG do not have absolute value for total phosphate and total nitrogen content rather provided relative value suggesting all surface waters should not be changed by greater than 15% from that of the water body under local, un-impacted conditions at time of the year. Likewise, USEPA have not set absolute value of total phosphate phosphorous and total nitrogen. Increase above 25 µg/l (0.025mg/l) total phosphate phosphorous in lake accelerate eutrophication and develop biological nuisances (Mackenthun,1973). Lake trigger to ultra-oligotrophic lake upon total phosphate phosphorous content below 0.004mg/l and trigger to oligotrophic lake upon phosphate content increase to 0.01mg/l (CWQG, 2008). Total phosphate content in Rara lake for the winter season ranged 0.01-5 mg/l implying Rara lake in the process of eutrophication . Dung of grazing horses at the lake riparian was noted. The mixing phosphorous content with melting ice during winter is assumed as the possible source. However,this will be further justified by regular seasonal water quality test result. Total nitrogen content in Rara lake for the winter season ranged 5.92-11.9 mg/l. Alike total phosphate phosphorous, NWQG total nitrogen content criteria as surface waters should not be changed by greater than 15% from that of the water body under local, un-impacted conditions at time of the year. Likewise, USEPA and CWQG have not set absolute Nitrogen value for freshwater/aquatic ecosystem. The toxic effects of total nitrogen are rarely occurred in nature hence restrictive criteria is not recommended. Ammonia concentration (0.04-0.11mg/l) in Rara lake appear much higher than recommended ammonia limit. NWQG suggested ammonia content should be below 7µg/l (0.007mg/l). Upon ammonia concentration increase to 15µg/l (0.015 mg/l), aquatic life suffers chronic effect and suffer by acute effect above 0.1 mg/l (µg/l). Concentration of ammonia acutely toxic to fishes cause loss of equilibrium, hyper-excitability, increase breathing, cardiac output and oxygen uptake and in extreme cases convulsions, coma and death. Decrease in water temperature and/or pH enhances to acute ammonia toxicity to aquatic life.

Lake riparian is providing nice space for various bird activities. However, discarded trashes were observed in the roosting and foraging site. In addition, Rara lake circuit trail is closed the riparian habitat. The human movement through the trail however has caused disturbance to waterfowl. Wetland dependent birds use multiple habitats since majority of wetland dependent birds are altitudinal migrants and anticipated these birds could be foraging in nearby farmland in Lamachour-Gamgadi area.Despite numerous trash pits (60) and trash bins (17) for safe disposal of trashes, the trashes are observed discarded in the trail and in the lake. Higher amount of trashes is in the trail surrounding the Rara Lake and some in the lake. Observed trash types are plastics, aluminum, garments and glass. The water quality test result for the season obtained showed phosphorous and ammonia concentration in Rara Lake above the permissible limit implying the lake in the process of eutrophication and acute ammonia toxicity affecting aquatic life. Ammonia content in aquatic ecosystem should be below 0.007mg/l (7microgram).

Conclusion

The study accounted a total of 2415 bird individuals from listed 104 species including 16 migratory Waterfowls. 13 wetland dependent and 75 forest birds.The observed waterfowls ranged from frequent and common to occasional and very uncommon winter visitor stop in Rara lake primarily for fueling during migration. Waterfowls are observed foraging majority of time congregating at shallow water and merely outside lakes since, lake riparian is highly productive and providing secure space for various activities. However, discarded trashes in the roosting and foraging site and around the lake circuit trail triggering threats to waterfowls and aquatic biodiversity while higher human movement through the trail causing disturbance to waterfowl. Phosphorous and ammonia concentration in Rara lake is crossed recommended level for freshwater/ aquatic ecosystem connoting lake in the process of eutrophication and acute ammonia toxicity affecting aquatic life. Higher human movement and trashes in the Rara lake trail seem to pose threat to aquatic biodiversity. Therefor trashes around the lake is required to be cleaned and in addition display board with instruction to visitors and trash pit/bin location map should be installed minimizing litter the area. Incineration of trashes would be environmental friendly rather than open burning of trashes in trash pits. Regular assessment of water quality is required preventing aquatic life from detrimental effects.

Acknowledgements

The authors extend gratitude towards USAID Paani Paani for funding the study project. Much thankful to Department of National Parks and Wildlife Conservation for providing permission to conduct the study. Sincere gratitude goes to Ishana Thapa, Bird Conservation Nepal for suggestion during the study project. And we are equally thankful to Rara National Park staff for their assistance and support during the study.

References

- APHA (1998). Standard Methods for the Examination of Water and Wastewater. 20th edition, American Public Health Association, Washington D.C.

- Baral, H.S. (2005). Avian fauna on the high altitude lakes of Nepal Himalayas. Pp 53-58. *In Bhandari, B.B. (2005). High altitude wetlands of Nepal: views and reviews on conservation. The proceedings of the national workshop on high altitude wetlands of Nepal. Forum of ecosystem management, Kathmandu.*

- Baral, H.S. (2007). Ornithological importance of the Gosainkunda Area. pp. 45-49. *In Bhandari, B. B. and Joo. G.J. (2007). Gosainthan: A sacred wetland in Nepal. Nepal Wetlands Society, Kathmandu.*

- Baral, H., & Bhandari, B. B. (2011). Importance of high altitude wetlands for protection of avian diversity in the Hindu Kush Himalayas. *TheInitiation*, *4*, 96–102.

- Battarbee, R. W. (2000). Palaeolimnological approaches to climate change, with special regard to the biological record. *Quat. Sci*. Rev., 19 107-124. https://doi.10.1016/S0277-3791(99)0007-8

- Battarbee, R. W., Grytnes, J., Thompson, R., Appleby, P. G., Catalan, J., Korhola, A. Briks, H.J.B, Heegaard, E., & Lami, A. (2002a). Comparing palaeolimnological and instrumental evidence of climate change for remote mountain lakes over the last 200 years. *Journal of Paleolimnology*, 28, 161–179. https://doi.org/10.1023/A:1020384204940

- Battarbee, R. W., Thompson, R., Catalan, J., Grytnes, J., & Birks, H. J. B. (2002b). Climate variability and ecosystem dynamics of remote alpine and arctic lakes: The MOLAR project. *Journal of Paleolimnology*, *28*, 1–6. https://doi.org/10.1023/A:1020342316326

- BCN& DNPWC. (2015). Birds of Rara-Checklist of Birds in and around Rara National Park. Bird Conservation Nepal.

- BCN & DNPWC. (2020). Birds of Rara National Park and its Buffer Zone Area. Published by Bird Conservation Nepal and Department of National Parks and Wildlife Conservation.

- Bibby, C. J., Burgess. N.D., Hill. D. A. and Mustoe. S.H. (2000). Bird census techniques-second edition, published in collaboration with Ecoscope- applied ecologists, British Trust for Ornithology, Royal Society for Protection of Birds and Birdlife International, 2000.

- Birdlife International (2020). Important Bird Areas Factsheet: Rara National Park. Downloaded from http://www.birdlife.org on 03/04/2020.
- Cantonati, M., Corradini, G., Jüttner, I., & Cox, E. J. (2001). Diatom assemblages in high mountain streams of the Alps and the Himalaya. *In Algae in Extreme Environments. Nova Hedwigia, Beiheft*, 123, 37–61.
- CBS (2008). Nepal Water Quality Guidelines for the protection of aquatic ecosystem, Environment statistics of Nepal, 2008. Government of Nepal, National Planning Commission Secretariat, Central Bureau of Statistics, Kathmandu, Nepal
- Chandan, P, Chatterjee, A., & Gautam, P. (2008). Management planning of Himalayan high altitude wetlands. A Case Study of Tsomoriri and Tsokar Wetlands in Ladakh, India. *In Proceedings of Taal 2007: The 12th World Lake Conference*, pp. 1446–1452.
- Chaudhary, H. (2015). Bird Survey in Rara National Park, October, 2015. Species list submitted to Bird Conservation Nepal, Unpublished.
- CWQG (2008). Canadian Water Quality Guidelines, 2008, Canadian Water Quality Guidelines for Protection of Aquatic life DHM (2018). Department of Hydrology and Meteorology. *In. Environment Statistics of Nepal, 2019. Government of Nepal, National Planning Commision, Central Bureau of Statistics, Thapathali, Kathmandu, Nepal.*
- DNPWC & BCN (2018) Birds of Nepal: An official Checklist, Kathmandu, Nepal
- Dubois, A. and Matsui, M. 1983. A new species of frog (Genus *Rana*, Subgenus *Paa)* from Western Nepal (Amphibia, Anura), *Copeia*, 1983:895-901. doi:10.2307/1445091.
- Ferro, W. (1978/1979). Some limnological and biological data from Rara, a deep Himalayan lake in Nepal. J.Nepal Res. Center 2/3: 241-261
- Galassi, S., Valsecchi, S., & Tartari, G. (1997). The distribution of PCB's and chlorinated pesticides in two connected Himalayan lakes. *WaterAir Soil Poll.*, *99*, 717–725.
- Grabherr, G., Björnsen Gurung, A., Dedieu, J. P., Haeberli, W., Hohenwallner,

D., Lotter, A. F., … Psenner, R. (2006). Long- term environmental observations in mountain biosphere reserves: recommendations from the EU- Project GLOCHAMORE. Mt. Res. Dev., 25(4), 376–382.

- Grimmett, R., Inskipp. C., Inskipp. T., & Baral, H.S. (2016) Birds of Nepal-Revised Edition, Bloomsbury Publishing India Pvt. Ltd, Vasant Kunj, New Delhi 110070
- Giri, T.R. 2005. Adopted from Important Bird Areas Factsheet: Rara National Park. Downloaded from http://www.birdlife.org on 03/04/2020.
- Harris, C., Bhandari, B. B., Hua, O., & Sharma, E. (2009). Himalayan wetlands initiative –conservation and wise use of natural water storage in the HKH region. Sustain. Mt. Dev., 56, 21–23.
- ICIMOD. (2015). International Centre for Integrated Mountain Development. Rara National Park. Retrieved from HKH Conservation Portal: http://hkhconservationportal.icimod.org/. Accessed 3rd March 2020.
- IUCN, 2020. Redlist of Threatened Species. iucnredlist.org. Accessed on 03 March 2020.
- Kapila, R., Kapila, Suman., and Basade, Y. (2002). Impact of Temperature variation on haematology and serum enzymes of *Schizothorax richardsonii* (Gray) (2002)., *Indian Journal of Fish*., 49 (2):187-192.
- Mackenthun, K.M. (1973) Toward a Cleaner Aquatic Environment. U.S. Environmental Protection Agency, Washington D.C.
- Mishra, C. & Humbert-Droz, B. (1998). Avifaunal survey of Tsomoriri Lake and adjoining Neuro Sumbo Wetland in Ladakh, Indian trans-Himalaya. Forktail 14:67-70.
- Okino, T. & Satoh, Y. (1986). Morphology, physics, Chemistry and Biology of Lake Rara in West Nepal. Hydrobiologia 140:125-133. https://doi.org/10.5702/massspec.39.301
- Ramsar, 2007. https://rsis.ramsar.org/ris/1695?language=en; Accessed on 3rd April 2020.
- Rupakheti, D., Tripathee, L., Kang, S., Sharma, C. M., Paudyal, R., & Sillanpää, M. (2017). Assessment of water quality and health risk for toxic trace elements in urban Phewa and remote Gosainkunda Lakes. Nepal. *Hum. Ecol*. Risk Assess.,

23(5), 959–973. https://doi.org/10.1080/10807039.2017.1292117

- Shannon, C.E., &Weaver, W. (1949). The Mathematical Theory of Communication. Urbana: University of Illinois Press

- Sharma, S., Bajracharya, R.M., Sitaula, B.K. & Merz, J. (2005). Water quality on the Central Himalaya. *Current Science*, Vol 89, No. 5.

- Swar, D.B. (1979). Report on single species of Cladocera from Rara lake, Nepal. J. Inst. Sci 2:185-190

- Terashima, A. (1984). Three new species of the Cyprinid Genus Schizothorax from Lake Rara, Northwestern Nepal. *Japanese Journal of Ichthyology*, Vol.31, No. 2

- Paani Project (2018). Water quality test result of Rara lake. USAID, Paani Project. Unpublished.

- USEPA, (1986). Quality Criteria for Water-1986. United States Environmental Protection Agency, Office of Water Regulations and Standards, Washington DC, 20460

- WHO,(2020).www.who.int/water_sanitation_health/resourcesquality/wpcchap2.pdf; Access on: 2 February 2020

- Yagi, H., Maemoku, H., Okamura, M., Matsuoka, H., Osada, T., Teramura,H., … Dangol, V. 2009. Rara Lake, its bathymetric feature and origin, Jumla District, western Nepal Himalayas *In: Project, Indus (Ed.), Annual Report of Environmental Change and the Indus Civilization 2009. Research Institute for Humanity and Nature, Kyoto*, pp. 59–62.

- Yasuda, Y., & Tabata, H. (1988). Vegetation and climatic changes in Nepal Himalayas, a preliminary study of the Holocene vegetation history in the Lake Rara National Park Area, West Nepal. *Proc. Indian Nat. Sci. Acad*., 54, 538–548.

Annex

Bird species sighted during the study time

S.N	Order/ Family/ Common Name	Scientific Name	Nepali Name	IUCN/Migratory Status
GALLIFORMES				
Phasianidae				
1	Chukar	*Alectoris chukar*	चुकर	LC, Ex(br)
2	Hill Partidge	*Arborophila torqueola*	पिउरा	LC, Ex(r)
3	Himalayan Monal	*Lophophorus impejanus*	डाफे	LC, Ex(r)
4	Kalij Pheasant	*Lophura leucomelanos*	कालिज	LC, Ex(br)
ANSERIFORMES				
Anatidae				
5	Greylag Goose	*Anser anser*	कलहाँस	LC, M(f), Ex(v)
6	Bar-headed Goose	*Anser indicus*	खोयाहाँस	LC, M(f), Ex(v)
7	Gadwall	*Mareca strepera*	खडखडे हाँस	LC, M(f), Ex(v)
8	Mallard	*Anas platyrhynchos*	हरियो टाउके हाँस	LC, M(f), Ex(v)
9	Red-crested Pochard	*Netta rufina*	सुनजुरे हाँस	LC, M(f), Ex(v)
10	Common Pochard	*Aythya ferina*	कैलोटाउके हाँस	VU, M(f), Ex(nbr)
11	Tufted Duck	*Aythya fuligula*	कालीजुरे हाँस	LC, M(f), Ex(v)
12	Goosander	*Mergus merganser*	मणितुण्डक	LC, M(f), Ex(v)
PODICIPEDIFORMES				
Podicipedidae				
13	Great crested Grebe	*Podiceps cristatus*	सिउरेडुबुल्कीचरा	LC, M(f), Ex(v)
14	Black-necked Grebe	*Podiceps nigricollis*	कालीकण्ठडुबुल्कीचरा	LC, M(f), Ex(v)
COLUMBIFORMES				
Columbidae				
15	Rock Pigeon	*Columba livia*	मलेवा	LC, Ex(r)
16	Snow Pigeon	*Columba leuconota*	हिमाली मलेवा	LC, M(f), Ex(r)
17	Oriental Turtle Dove	*Streptopelia orientalis*	तामे ढुकुर	LC, M(f), Ex(br)

CAPRIMULGIFORMES				
Caprimulgidae				
18	Grey Nightjar	*Caprimulgus (indicus) jotaka*	फुस्रो चैतेचरा	LC, M(f), Ex(r)
GRUIFORMES				
Rallidae				
19	Common Moorhen	*Gallinula chloropus*	बगाले सिमकुखुरा	LC, M(f), Ex(v)
20	Eurasian Coot	*Fulicia atra*	मरुल	LC, M(f), Ex(r)
PELECANIFORMES				
Ardeidae				
21	Black-crowned Night Heron	*Nycticorax nycticorax*	बाके बकुल्ला	LC, M(f), Ex(v)
SULIFORMES				
Phalacrocoracidae				
22	Great Cormorant	*Phalacrocorax carbo*	जलेवा	LC, M(f), Ex(nbr)
CHARADRIIFORMES				
Scolopacidae				
23	Common Snipe	*Gallinago gallinago*	पानी चाहा	LC, M(f), Ex(nbr)
24	Common Redshank	*Tringa totanus*	लालखुट्टे टिमटिमा	LC, M(f), Ex(v)
25	Green Sandpiper	*Tringa ochropus*	रुख सुड्सुडिया	LC, M(f), Ex(v)
26	Common Sandpiper	*Actitis hypoleucos*	चञ्चले सुडसुडिया	LC, M(f), Ex(v)
Laridae				
27	Lesser Black-backed Gull	*Larus fuscus*	हिउग्लिन गंगाचील	LC, M(f), Ex(v?)
28	Pallas's Gull	*Larus ichthyaetus*	राजा गंगाचील	LC, M(f), Ex(v)
29	Brown-headed Gull	*Larus brunnicephalus*	खैरोटाउके गंगाचील	LC, M(f), Ex(nbr)
STRIGIFORMES				
Strigidae				
30	Mountain Scops-owl*	*Otus spilocephalus*	लेकाली उलूक	LC, M(a), Ex(br)
31	Himalayan Owl	*Strix nivicolum*	कैलो पहाडी उलूक	LC, Ex(r)
ACCIPITRIFORMES				
Accipitridae				
32	Black Kite	*Milvus migrans*	कालो चील	LC, M(f), Ex(r, br?)

33	Himalayan Vulture	*Gyps himalayensis*	हिमाली गिद्ध	LC, M(f), Ex(r, br?)
34	Eurasian Marsh-harrier	*Circus aeruginosus*	पूर्वीय सिम भुईचील	LC, M(f), Ex(v)
35	Bearded Vulture	*Gypaetus barbatus*	हाडफोर	NT, Ex(r,br?)
36	Himalayan Buzzard	*Bueto b. burmanicus*	श्येनबाज	LC, Ex(r)
37	White-tailed Sea-Eagle *	*Haliaeetus albicilla*	कङ्कम चील	LC, M(f), Ex(nbr)
CORACIIFORMES				
Alcedinidae				
38	Crested Kingfisher	*Megaceryle lugubris*	ठुलोछिरबिरेमाटीकोरे	LC, M(a), Ex(br)
PICIFORMES				
Picidae				
39	Himalayan Woodpecker	*Dendrocopos himalayensis*	हिमाली काष्ठकूट	LC, Ex(r)
40	Scaly-bellied Woodpecker	*Picus squamatus*	ठूलोकत्ले काठफोर	LC, Ex(br)
CARIAMIFORMES				
Falconidae				
41	Common Kestrel	*Falco tinnunculus*	बौडाइ	LC, M(f), Ex(br)
42	Peregrine Falcon*	*Falco peregrinus*	शाही बाज	LC, M(f), Ex(br)
PASSERIFORMES				
Vireonidae				
43	Green Shrike-babbler*	*Pteruthius xanthochlorus*	हरित भद्राईभ्याकुर	LC, M(a), Ex(r)
Laniidae				
44	Grey-backed Shrike	*Lanius tephronotus*	हिमाली भद्राई	LC, M(f), Ex(r)
Corvidae				
45	Yellow-billed Blue Magpie	*Urocissa flavirostris*	सुनठूडे लामपुच्छे	LC, M(a), Ex(r)
46	Southern Nutcracker	*Nucifraga hemispila*	वनसर्रा	LC, Ex(br)
47	Yellow-billed Chough	*Pyrrhocorax graulus*	टेमु	LC, Ex(r)
48	Large-billed Crow	*Corvus macrortynchos*	कालो काग	LC, Ex(r)

Stenostiridae				
49	Yellow-bellied Fairy-fantail	*Chelidorhynx hypoxanthus*	पहेलो मारुनीचरी	LC, M(a), Ex(r)
Paridae				
50	Great Tit	*Parus major*	चिचिल्कोट	LC, Ex(r)
51	Green-backed Tit	*Parus monticolus*	हरियो चिचिल्कोटे	LC, M(a), Ex(r)
52	Coal Tit	*Periparus ater*	सानो फुस्रे चिचिल्कोटे	LC, Ex(r)
53	Grey-crested Tit	*Lophophanes dichrous*	फुस्रोजुरे चिचिल्कोटे	LC, Ex(r)
Alaudidae				
54	Oriental Skylark	*Alauda gulgula*	ब्राह्मीचटी	LC, M(f), Ex(r)
Hirundinidae				
55	Barn Swallow*	*Hirundo rustica*	घर गौथली	LC, M(f), Ex(br)
56	Eurasian Crag Martin	*Ptyonoprogne rupestris*	नहिकुटी गौथली	LC, M(f), Ex(br)
Pycnonotidae				
57	Himalayan Bulbul	*Pycnonotus leucogenys*	जुल्फे जुरेली	LC, M(f), Ex(r)
58	Black Bulbul	*Hypsipetes leucocephalus*	बाखे जुरेली	LC, M(f), Ex(r)
Phylloscopidae				
59	Lemon-rumped Leaf-warbler	*Phylloscopus chloronotus*	पीतकटी फिस्टो	LC, M(a), Ex(r)
Aegithalidae				
60	White-throated Tit	*Aegithalos niveogularis*	सेतोकण्ठे राजचिचिल्कोटे	LC, Ex(br)
61	Red-headed Tit	*Aegithalos iredalei*	कालीकण्ठे राजचिचिल्कोट	LC, Ex(r)
Sylviidae				
62	White-browed Fulvetta	*Fulvetta vinipectus*	पीतनयन फूलबुट्टा	LC, M(a), Ex(r)
Zosteropidae				
63	Oriental White-eye	*Zosterops palpebrosus*	कांकीर	LC, Ex(r)
64	Stripe-throated Yuhina	*Yuhina gularis*	थुपलकल्की जुरेचरा	LC, M(a), Ex(r)
Leiotrichidae				
65	Variegated Laughingthrush	*Trochalopteron variegatum*	टिकीयुर तोरीगाँडा	LC, Ex(r)
66	Spotted Laughingthrush	*Garrulax ocellatus*	मुँदाले तोरीगाँडा	LC, Ex(r)

67	Streaked Laughingthrush	*Trochalopteron lineatum*	छिर्के तोरीगाँडा	LC, Ex(r)
68	Chestnut-crowned Laughingthrush	*Trochalopteron erythrocephalum*	कटुसटाउके तोरीगाँडा	LC, Ex(r)
69	Rufous Sibia	*Heterophasia capistrata*	सिबिया	LC, Ex(r)
Certhiidae				
70	Hodgson's Treecreeper	*Certhia hodgsoni*	सेतोपेटे छेपारेचरी	LC, Ex(r)
Sittidae				
71	Kashmir Nuthatch	*Sitta cashmirensis*	काश्मीरी मट्टा	LC, Ex(r)
72	White-cheeked Nuthatch	*Sitta leucopsis*	कालोटाउके मट्टा	LC, Ex(r)
73	Wallcreeper	*Tichodroma muraria*	मुरारी पुतलीचरा	LC, Ex(r)
Troglodytidae				
74	Northern Wren	*Troglodytes troglodytes*	चित्री	LC, M(f), Ex(br)
Cinclidae				
75	Brown Dipper	*Cinclus pallasii*	खैरो वञ्जूल	LC, Ex(r)
Turdidae				
76	Alpine Thrush	*Zoothera mollissima*	सादाढाडे चाँचर	LC, M(a), Ex(r)
77	White-collared Blackbird	*Turdus albocinctus*	कण्ठे चाँचर	LC, M(a), Ex(r)
78	Black-throated Thrush	*Turdus atrogularis*	कालोकण्ठे चाँचर	LC, M(f), Ex(nbr)
Muscicapidae				
79	Himalayan Bush-robin	*Tarsiger rufilatus*	सुन्तलाकोखे रबिन	LC, M(f), Ex(r)
80	Rufous-bellied Niltava	*Niltava sundara*	सुन्दर नीलतभा	LC, Ex(r)
81	Blue-fronted Redstart	*Phoenicurus frontails*	नीलटाउके खञ्जरी	LC, M(a), Ex(r)
82	Blue-capped Redstart	*Phoenicurus coeruleocephala*	धोबिनी खञ्जरी	LC, M(a), Ex(r)
83	Grey Bushchat	*Saxicola ferreus*	हिमाली भ्याप्सी	LC, Ex(r)
84	Common Stonechat	*Saxicola torquatus*	भेकभेक भ्याप्सी	LC, M(f), Ex(br)
85	Blue Whistling Thrush	*Myoponus caeruleus*	कल्चौडे	LC, M(a), Ex(br)

85	White-capped Water-redstart	*Chaimarrornis leucocephalus*	सेतोटाउके जलखञ्जरी	LC, M(a), Ex(r)
87	Plumbeous Water Redstart	*Rhyacornis fuliginosus*	नीलाम्बर जलखञ्जरी	LC, Ex(r)
88	Spotted Forktail	*Enicurus scouleri*	थोप्ले खोलेधोबिनी	LC, Ex(r)
Regulidae				
89	Goldcrest	*Regulus regulus*	स्वर्णचूल फिस्ट	LC, M(f), Ex(r)
Prunellidae				
90	Rufous-breasted Accentor	*Prunella strophiata*	मुसे लेकचरी	LC, Ex(r)
Passeridae				
91	Russet Sparrow	*Passer rutilans*	कैलो भँगेरा	LC, M(a), Ex(r)
92	Eurasian Tree Sparrow	*Passer montanus*	रुख भँगेरा	LC, Ex(br)
Motacillidae				
92	Upland Pipit	*Anthus sylvanus*	पहाडी चुइयाँ	LC, Ex(r)
94	Tree Pipit*	*Anthus trivialis*	बगाले चुइयाँ	LC, M(f), Ex(r)
95	White Wagtail	*Motacilla alba*	फुस्रो टिकटिके	LC, Ex(br)
Fringillidae				
96	Common Chaffinch	*Fringilla coelebs*	चित्रकचरी	LC, M(f), Ex(r)
97	White-winged Grosbeak	*Mycerobas carnipes*	धूपी महाँठूँड	LC, M(f), Ex(r)
98	Plain Mountain Finch	*Leucosticte nemoricola*	तितुभँगेरा	LC, M(f), Ex(r)
99	Yellow-breasted Greenfinch	*Chloris spinoides*	गाजले पीतचरी	LC, M(f), Ex(r)
100	Common Rosefinch	*Carpodacus erythrinus*	अमोंगा तितु	LC, M(f), Ex(br)
101	Pink-browed Rosefinch	*Carpodacus rodochroa*	रातो भिÞबी तितु	LC, M(a), Ex(r)
102	Red-fronted Serin	*Serinus pusillus*	लालमाथा सिरिन	LC, M(a), Ex(br)
103	Eastern Goldfinch	*Carduelis carduelis*	रक्तमुहार पीतचरी	LC, M(f), Ex(r)
104	Red-headed Bullfinch	*Pyrrhula erythrocephala*	रातोटाउके टिउँटिउ	LC, M(a), Ex(r)

* New Species record for Rara National Park

LC-Least Concern; NT-Near Threatened; M(f)-Full Migrant; M(a)-Altitudinal Migrant; Ex(nbr)-Extent non-breeding; Ex(v)-Extent visitor; Ex(r)-Extent Resident; Ex(br)- ?-Information from Nepal not mentioned in IUCN Redlist of Threatened Species

Carlson's Trophic State Index for the Assessment of Trophic state of Phewa, Begnas and Rupa Lakes in Kaski district, Nepal

Shristi Shrestha[1*], Rabin Malla[1]
[1]Center of Research for Environment, Energy and Water (CREEW), Baluwataar
*Corresponding email: shresthashristi02@gmail.com

Abstract

Eutrophication of wetlands has been considered as a global level environmental problem due to wide range of environmental impacts caused by it. All the lake bodies are subjected to natural eutrophication process but anthropogenic activities like excessive utilization of inorganic fertilizers containing phosphorus and nitrogen in the farmlands which ultimately reach to water bodies through runoff during rainfall further maximizes the eutrophication.The research was conducted to find the trophic state of Lake Phewa, Lake Begnas and Lake Rupa which are three major lakes of Lake Clusters of Pokhara Valley, a Ramsar listed wetland from mid-hills of Nepal.Trophic state of lakes were classified on the basis of Carlson's Trophic State Index. This index was calculated with the measurement of Secchi depth, Chlorophyll-a, and Total Phosphorus using standard methods. Study revealed that all three lakes were mesotrophic in both pre-monsoon and monsoon season. Lake Rupa had the highest Carlson Trophic State Index (CTSI) and Lake Begnas had lowest CTSI in both the season. Development of lake from oligotrophic to eutrophic state is a natural and gradual process and hence these lakes have increased chances of being eutrophic naturally along with natural process being crucially altered by cultural eutrophication which shortens the life expectancy of the affected aquatic body. Suitable conservation measures are needed to reduce organic load from lake to prevent from being further degraded.

Keywords: *Chlorophyll a, Eutrophication, Secchi depth, Total Phosphorus, Trophic State*

Introduction

Lake eutrophication is a natural process as lake ages (Carpenter, 1981) but increased human activities involving excessive utilization of inorganic fertilizers (mainly nitrogen and phosphorus) which ultimately reach to lake water bodies through runoff during precipitation (Ghosh and Mondal, 2012; Schindler, 2012) is maximizing the rate of eutrophication commonly being known as cultural eutrophication. As a result of which globally eutrophication has been recognized as major threat to health of aquatic ecosystems (Carpenter, 2005; Schindler, 2012; Wilkinson, 2017) where lake constitute the major portion of them (Selman and Greenhalgh, 2010). With increase in nutrient and organic load the lake bodies transform from oligotrophic to mesotrophic and finally to eutrophic. Eutrophication excessively increases phytoplankton growth resulting in algal blooms (González and Roldán, 2019), habitat loss, decreased dissolved oxygen concentration (Smith and Schindler, 2009) which further can have serious environmental and socio-economic impacts (Khan and Mohammad, 2014). Hence, assessment of lake water bodies in terms of eutrophication status is essential component in water quality assessment (Karmakar and Musthada, 2013) as well as for its conservation planning and management strategies (Sharma *et al*., 2010; Opiyo *et al*., 2019).

Eutrophication assessment can be easily carried out by determining trophic status of water bodies (Quevedo-Castro *et al*., 2019) which involves determination of concentration of nutrients and classifying the trophiclevel based on their concentration (Bekteshi and Cupi, 2014). Determining trophic state index (TSI) is essential attribute in scientific assessment as it indicates the ecological integrity and water quality (Dodds, 2007) of water bodies' use for various purposes. Furthermore TSI helps to understand biotic and abiotic condition of water body, relation between bio-chemical parameters and condition of the lake in relation to human requirement and usefulness (Carlson and Simpson, 1996; Wetzel, 2001; Matthews *et al*., 2002).

The most common and classical method of determining TSI is Carlson Trophic State Index (CTSI) which was developed by Carlson in1977. CTSI involves use of parameters namely Chlorophyll-a (Chl-a), Total Phosphorus (TP) and Secchi Depth (SD)for determining TSI (Carlson, 1977).

Freshwater bodies across Nepal are reported to show nutrient enrichment (Gurung *et al*., 2019). Lake Phewa, Lake Begnas and Lake Rupa are three major water bodies of Ramsar Site namely Lake Clusters of Pokhara Valley upon which a large portion of population residing in the periphery of these lakes are dependent for their livelihood. These lakes have high biodiversity and recreational value but are under numerous environmental stresses. In addition continuous monitoring of their trophic status is still not considered. Hence, the study seeks to find the eutrophication status of three big lakes of Lake Clusters of Pokhara Valley so that outcome can be strong evidence for formulation of suitable plan, policy or program for sustainable management and conservation of these lake water bodies. Conservation measures needed to adopt for to avoid from lake from being further degraded from eutrophication perspective has also been recommended in the paper.

Materials and Methods

Study Area

The study was conducted in three major lakes of Lake Clusters of Pokhara Valley namely Lake Phewa, Lake Begnas and Lake Rupa which lies in Gandaki province (Figure 1.). The detailed information regarding geographical location, catchment area, water body areas etc. of individual lakes are presented in Table1.LCPV has humid subtropical climate with summer temperature between 25°C and 35°C and winter temperature from -2°C to 15°C. The lakes are highly important from environmental, social and economic viewpoint as Lake Phewa and Lake Begnas are the most famous touristic destination in Pokhara valley. Individual lakes play important regional hydrological role in contributing to groundwater recharge, flood control, sediment trapping etc. (DNPWC & IUCN, 2016). The lake area is reported to be habitat to globally threatened and endangered endemic flora and fauna like *Alstonia scholaris; Apostasia wallichii, Michelia champaca, Bulbophyllum plyrhiza, Cymbidium iridioides, Dendrobium densiflorum, D. fimbiatum*, *Cyathea spinosa, Dioscorea deltoidea; Oberonia nepalensis; O. iridifolia; Oroxylum indicum, Papilionantheteres sp., Oryza rufipogon , Tinospora sinensis , Ceratophyllum demersum, Trapa natans*, *Typha angustifolia.* The lakes host several globally threatened migratory birds and several mammals like Spiny Babbler (*Turdoides nepalensis*), Nepal Wren Babbler (*Pnoepyga immaculate*), Comb duck (*Sarkidiornis melanotos*), Baer's Pochard (*Aythya baeri*), Ferruginous Duck (*Aythya nyroca*), common otter (*Lutra lutra*) etc. (MoFE, 2018).

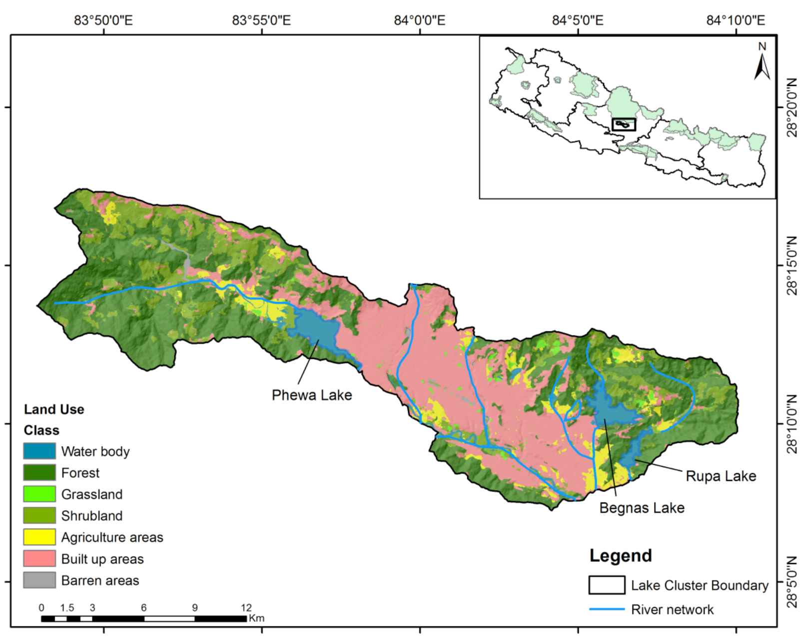


Figure 1: Map showing Lake Phewa, Lake Begnas and Lake Rupa

Table1. Detailed information on Lake Phewa, Lake Begnas and Lake Rupa

S.N.	Lake	Metropolitan City/Rural Municipality	Geographical coordinates	Altitude (m)	Catchment area (km^2)	Water body area (km^2)	% of area covered by water body
1	Phewa	Pokhara Lekhnath Metropolitan City Annapurna Rural Municipality	28.1943-28.2902 83.8004-83.9898	762 – 2,482	119.39	4.33	3.6
2	Begnas	Pokhara Lekhnath Metropolitan	28.1621-28.2167 84.0814-84.1332	647-1447	18.40	3.13	16.8
3	Rupa	Pokhara Lekhnath Metropolitan City Rupa Rural Municipality	28.139-28.2061 84.1004-84.1699	580-1420	27.60	1.11	4.3

Methodology

Sample collection and transportation

Sampling was done during September 2019. A total 10 lake water sample was collected from each lake so that the sample would be representative for whole lake. Secchi depth was measured directly on site and from the point where Secchi depth was measured water samples for analysis of Total Phosphorus and Chlorophyll a was collected in polyethylene bottles. The water samples were preserved in ice box at the sampling site, refrigerated at 4°C during field sampling days and immediately transferred to laboratory within 2 days.

Water sample analysis

Secchi depth was determined by Secchi disk method before water sample collection. A Secchi disc of size 20centimeter in diameter was used for Secchi depth determination. The disc was slowly lowered into the water body until it disappeared and the depth was noted. The disk was lowered a few more centimeters and then was slowly raised again until it reappeared and the second reading of depth was also noted. The average of these two readings was taken as the final Secchi disc visibility depth (APHA, 1995).

Total phosphorus was analyzed by digestion method. The water sample was digested with Nitric acid and Sulphuric acid followed by determining the phosphorus content by stannous chloride method. The absorbance of blue color complex was formed which was measured at 690nm using spectrophotometer (6715 UV/Vis Spectrophotometer JENWAY). Finally, the concentration of phosphorus was determined from the standard curve (APHA, 1989) prepared.

Chlorophyll a was estimated by Trichromatic method and using spectrophotometric procedure (APHA, 1989) (Table 2.)

Table 2. Parameters and methods followed for field and laboratory analysis

S.N.	Parameters	Method involved	Materials involved	Reference
1	Secchi depth	Secchi disk method	Secchi disk	APHA, 1995
2	Total Phosphorus	Digestion with nitric acid and sulphuric acid followed by stannous chloride method	Spectrophotometer (6715 UV/Vis Spectrophotometer JENWAY)	APHA, 1989
3	Chlorophyll a	Trichromatic method and using spectrophotometric procedure	Spectrophotometer (6715 UV/Vis Spectrophotometer JENWAY)	APHA, 1989

Assessment of CTSI

Trophic status of lake was determined by using CTSI. Trophic state determines how green the lake is and is measured by algae biomass amount in the water. Oligotrophic, mesotrophic and eutrophic are three trophic state categories as they grow progressively greener. Among the various methods identified for determining TSI of lake, CTSI is one of the popular and mostly used methods that takes into account measurement of variables namely total phosphorus, chlorophyll a and Secchi depth. The following equations are used to determine CTSI:

TSI (P) = 14.42 ln TP (μg/l) + 4.15 …………………….. (i)

TSI (Chl) = 9.81 ln Chl-a (μg/l) + 30.6 …………………….. (ii)

TSI (SD) = 60 – 14.41 ln SD (meters) …………………... (iii)

Average TSI = [TSI (P) + TSI (Chl) + TSI (SD)] /3 …………………… (iv)

Where, TP = Total phosphorus

Chl-a = Chlorophyll a

SD = Secchi Depth

In = natural log

Based on the obtained values of CTSI, lakes are classified as oligotrophic (low productive), mesotrophic (moderately productive) and eutrophic (highly productive).

The range of CTSI values and classification of lakes are presented in the Table 3.

Data Analysis and Interpretation

Data analysis was done in Statistical Package for the Social Sciences (SPSS) and the results are presented in tabular and radar diagram.

Table 3: TSI Values and Corresponding Carlson Trophic State

TSI Value	Trophic Status	Attributes
<30	Oligotrophic	Clear water, oxygen throughout the year in the hypolimnion
30-40	Oligotrophic	A lake will still exhibit oligotrophy, but some shallower lakes will become anoxic during the summer
40-50	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
50-60	Eutrophic	Lower boundary of classical eutrophy: Decreased transparency, warm-water fisheries only
60-70	Eutrophic	Dominance of blue-green algae, algal scum probable, extensive macrophyte problems
70-80	Hyper eutrophic	Heavy algal blooms possible throughout the summer, often hypereutrophic
>80	Hyper eutrophic	Algal scum, summer fish kills, few macrophytes

Source: Carlson and Simpson, 1996

Results and Discussion

Analysis of CTSI of three big lakes namely Phewa, Begnas and Rupa revealed that all the three lakes were mesotrophic in both pre-monsoon and monsoon season. Among three lakes Lake Rupa had highest CTSI value of 43.53 and 42.82 in pre-monsoon and monsoon season respectively while Lake Begnas had lowest CTSI value of 42.16 and 41.46 in pre-monsoon and monsoon season respectively (Table 4). According to CTSI value and corresponding trophic state of the lake it is revealed that water of the lakes are moderately clear but there are increasing chances of anoxia during summer (Table 3 and 4). Monsoon TSI is comparatively lower than pre-monsoon TSI which might be due to more amount of rainfall in monsoon season than in pre-monsoon season which might have diluted the chemical concentration in lake water bodies. Also, Pokhara valley receives highest amount of rainfall in the country with reference record of 5244mm average annual precipitation in Lumle (Luitel *et al*., 2020).

Our result which reported mesotrophic characteristics of the lakes didn't clash with other results as Nakanishi *et al*. (1982) reported that the Fewa Lake is oligomesotrophic and Begnas and Rupa Lake are eutrophic based on the total phosphorus concentration. Rai (2000) classified these three lakes as oligoeutrophic based on the chlorophyll a content. This might be due to the reason that trophic state of lake depends mostly on precipitation and use of water by farmers for irrigation (Rai, 2000)

Waters from these lakes has been largely used for drinking purpose especially from Begnas (MOFE, 2018) also evidenced by the lowest CTSI value of Lake Begnas. In the past the lakes mainly Phewa resulted in high algal bloom and mass fish kills but during research period Phewa had very few algal blooms and also the water was mesotrophic. This might be due to various local conservation initiatives carried out by local people for lake conservation. As Lake Rupa has highest CTSI among the three which might be due to frequent human activities like cleaning and washing dishes, clothes, bathing in the lake which was evidenced in the field days.

All the three lakes are currently in the early mesotrophic state as per CTSI but the developmental process of lake being eutrophic from oligotrophic is very natural process but often accelerated by various anthropogenic induced factors (Steffanson *et al*., 2001; Sharma *et al*., 2010). Various environmental stresses that would degrade the lake quality were seen in the field days. The similar environmental stress like pollutants runoff from agricultural chemicals, sewages, waste disposal (solid and liquid) etc. has been reported by various other researches too (MOFE, 2018). Various other researches also reported environmental pressures like encroachment, sedimentation, alien species invasion, land use change and other driving forces like weak wetland governance, policy overlapping etc. in the lakes (DNPWC & IUCN, 2016; Husen & Dhakal, 2009; MOFE, 2018; Pant *et al*., 2019). Such trend finally leading to cultural eutrophication significantly alters natural process and shortens life expectancy of lake water bodies.

Table 4: CTSI of Lake Phewa, Begnas and Rupa in pre-monsoon and monsoon season

S.N.	Lake cluster name		SD (m)	TP (µg/l)	Chl-a (µg/l)	TSI (SD)	TSI (TP)	TSI (Chl-a)	TSI	Trophic Status	Specific attributes of the trophic status of the lakes as per CTSI
Pre-monsoon analysis											
1	Phewa	Mean ± S.E	1.68 ± 0.05	2.90 ± 0.22	4.35 ± 0.34	52.83	19.15	55.89	42.62	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
2	Begnas	Mean ± S.E	1.58± 0.01	2.78 ± 0.16	4.17 ± 0.25	53.39	18.68	54.40	**42.16**	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
3	Rupa	Mean ± S.E	0.96± 0.04	4.43 ± 0.43	6.65 ± 0.64	60.63	24.98	44.90	**43.53**	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
Monsoon analysis											
1	Phewa	Mean ± S.E	1.37 ± 0.01	2.36 ± 0.14	3.55 ± 0.21	55.44	16.30	54.94	42.24	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
2	Begnas	Mean ± S.E	1.70± 0.01	2.61 ± 0.18	3.91 ± 0.27	52.29	17.67	54.09	**41.46**	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
3	Rupa	Mean ± S.E	0.94± 0.01	2.40 ± 0.20	3.61 ± 0.30	60.92	16.33	51.20	**42.82**	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer

Conclusion and Recommendations

Trophic state monitoring is crucial part in assessing and managing lake ecosystems. CTSI values recorded for Lake Phewa, Begnas and Rupa were in between 40 – 45. Based on Carlson TSI, Lake Phewa, Begnas and Rupa were classified as mesotrophic in both pre-monsoon and monsoon season. But the lake can show the increased tendency becoming anoxia in the summer.

Development of lake from oligotrophy to eutrophic state is a natural and gradual process which is based on the changes in the degree of nutrient flow and productivity in the lake. This natural process is crucially altered by cultural eutrophication which shortens the life expectancy of the affected aquatic body. All three lakes were mesotrophic during the research period. As mentioned earlier these lakes have increased chances of being eutrophic naturally along with various anthropogenic factors being involved in it suitable conservation measures is needed to be adopted for to avoid from lake being degraded.

- Regular manual or automatic cleaning of macrophytes and algal biomass should be done to prevent these lake water bodies from being degraded
- Involve citizen scientists, volunteers for water conservation programs to educate common man regarding threats to water body and conservation strategies that can be adopted
- Control of pollution at source through removal and control of point sources, diversion of nutrients
- In lake treatment method through treatment and control measures like dredging, nutrient inactivation/ precipitation, chemical and biological control of nuisance organisms etc.
- Formulation of legal framework, specific laws regarding non-point sources
- Integrated Lake Basin Management (ILBM) approach to attain sustainable management through spatially and thematically holistic integrated approach

Acknowledgements

The authors would like to thank Center of Research for Environment, Energy and Water (CREEW) for funding first author for the research work.

References

- APHA (1989). Standard Methods for the Examination of Water and Wastewater, Part 3, Determination of Metals. 17th, American Public Health Association, Washington DC, 164.
- APHA (1995). Standard Methods for the Examination of Water and Wastewater. 19th Edition, American Public Health Association Inc., New York.
- Bekteshi, A. & Cupi, A. (2014). Use of trophic state index (Carlson, 1977) for assessment of trophic status of the Shkodra Lake. *Journal of Environmental Protection and Ecology*, 15(1), 359-365.
- Carlson R.E. & Simpson J. (1996). A Coordinator's Guide to Volunteer Lake Monitoring Methods. North American Lake Management Society, 96 pp.
- Carlson, R.E. (1977). A Trophic State Index for Lakes. Limnology and Oceanography, 22, 361-369. https://doi.org/10.4319/lo.1977.22.2.0361.Carpenter, S. R. (1981). Submersed vegetation: an internal factor in lake ecosystem succession. *The American Naturalist*, 118(3), 372-383.
- Carpenter, S. R. (2005). Eutrophication of aquatic ecosystems: Bistability and soil phosphorus. Proceedings of the National Academy of Sciences of the United States of America, 102(29), 10002.
- DNPWC & IUCN (2016). Lake Clusters of Pokhara valley. Department of National Parks and Wildlife Conservation. International Union for Conservation of Nature. Kathmandu, Nepal.
- Dodds, W.K. (2007). Trophic state, eutrophication and nutrient criteria in streams. Trends in *Ecology & Evolution*, 22(12): 669-676
- Ghosh, T. G. & Mondal, D. (2012). Eutrophication: Causative Factors and Remedial Measures. *J Today Biol Sci Res Rev (JTBSRR)*, 1 (1), 153.
- González, E.J. and G. Roldán (2019). Eutrophication and phytoplankton: some generalities from lakes and reservoirs of the Americas. In: M. Vítová (ed.). Microalgae from Physiology to Adaptation. IntechOpen, http://dx.doi. org/10.5772/intechopen.89010.
- Gurung, S., kafle, B.K., Dahal, B.M, Sthapit, M., Raut, N., Sharma, C.M, Kafle, C.M and Manandhar, S. (2019). Trophic Status of Lake Phewa and Kulekani Reservoir,

Nepal. *Asian Journal of Water, Environment and Pollution*, Vol. 18, No. 3 (2021), pp. 49–57. DOI 10.3233/AJW210028

- Husen, M. A. & Dhakal, R.P. (2009). Seasonal variations of Zooplankton, chlorophyll – a and nutrienrs in Phewa Lake, Pokhara Valley, Nepal. ECOPRINT, 16, 51- 57.

- Karmakar, S. and O.M. Musthafa (2013). Lakes and reservoirs: Pollution. In: Encyclopedia of Environmental Management. Taylor and Francis: New York, doi:10.1081/ E-EEM-120047215.

- Khan, M.N. and F. Mohammad (2014). Eutrophication: Challenges and solutions. In: A. Ansari and S. Gill (Eds.), Eutrophication: Causes, consequences and control. Dordrecht, *Springer*, 261 p.

- Luitel, D.R., Jha, P.K., Siwakoti, M., Shrestha, M.L. & Munniappan, R. (2020). Climatic Trends in Different Bioclimatic Zones in the Chitwan Annapurna Landscape, Nepal. Climate, 8, 136. https://doi.org/10.3390/cli8110136.

- Matthews R., Hilles M. & Pelletier G. (2002). Determining trophic state in Lake Whatcom, Washington (USA), a soft water lake exhibiting seasonal nitrogen limitation, *Hydrobiologia* , 468, 107-121.

- MoFE (2018). Integrated Lake Basin Management Plan of Lake Cluster of Pokhara Valley, Nepal (2018-2023). Ministry of Forests and Environment, Kathmandu, Nepal.

- Nakanishi, M., Terashima, A., Watanabe, M. & Mishra, P.N. (1982). Preliminary report on limnological survey in lakes of the Pokhara Valley (Nepal) in November-December, 1982. In: Kadota H (ed) Expedition report in Nepal, 31-41 pp.

- Opiyo, S., Getabu, A. M., Sitoki, L. M., Shitandi, A., & Ogendi, G. M. (2019). Application of the carlson's trophic state index for the assessment of trophic status of lake simbi ecosystem, a deep alkaline-saline lake in Kenya. *International Journal of Fisheries and Aquatic Studies*, 7(4), 327–333.

- Quevedo-Castro, A., Bandala, E.R., Rangel-Peraza, J.G., Amábilis-Sosa, L.E., Sanhouse-García, A. and Y.A. Bustos-Terrones (2019).Temporal and spatial study of water quality and trophic evaluation of a large tropical Reservoir. *Environments*, 6(6): 61. doi:10.3390/ environments6060061

- Rai, A.K. (2000). Limnological characteristics of subtropical lakes Phewa, Begnas and Rupa in Pokhara Valley, Nepal. *Limnology*, 1, 33-46.

- Schindler, D. W. (2012). The dilemma of controlling cultural eutrophication of lakes. *Proceedings. Biological Sciences / The Royal Society*, 279(1746), 4322–4333.
- Selman, M. & Greenhalgh, S. (2010). Eutrophication: Sources and drivers of nutrient pollution. *Renewable Resources Journal*. 26 (4): 19-26.
- Sharma, M., Kumar, A., & Rajvanshi, S. (2010). Assessment of trophic state of lakes: A case of mansi ganga lake in India. *Hydro Nepal: Journal of Water, Energy and Environment*, 6, 65–72.
- Smith, V.H. and D.W. Schindler (2009). Eutrophication science: Where do we go from here? *Trends in Ecology & Evolution*, 24(4): 201-207
- SteffansonC, Rose I and Nvoelz (2001). Trophic State Index measurements for six stems county lakes during June-September,2001. Reports to stems county. *Environmental Pub*. PP.14
- Wetzel R. G. (2001). Limnology: Lake and River Ecosystems, Academic Press, San Diego, California, 1006 pp.
- Wilkinson, G. M. (2017). Eutrophication of Freshwater and Coastal Ecosystems. Modile in Earth Systems and Environmental Sciences. *Elsevier*, 102-321.

Rainwater Harvesting Practices and Its Effectiveness in Kathmandu Metropolitan City

Kenisha Shrestha[1], Pranil Pradhan[1*], Prakash Chandra Wagle[1], Prashansha Pokharel[1]
[1]GoldenGate International College, Tribhuvan University, Kathmandu Nepal
[*]Corresponding email: ppranil401@gmail.com

Abstract

Water scarcity has been a major problem of Kathmandu Metropolitan City (KMC). Different interventions are being attempted to solve this problem including the highly discussed Melamchi Drinking Water supply project. Thus, so rainwater harvesting (RWH) could be a promising approach to satisfy water to some extent.The study has aimedto assess the status of rainwater harvesting practices in KMC and to examine itseffectivenessin overcoming the water shortage.A total of 244 households were surveyed covering 32 wards of KMCthrough random sampling method and semi structured questionnaire forms were laid for the data collection. The annualrainfall data of interval 30 years (1990-2019) of KMC,collected from department of Hydrology and Meteorology for trend analysis. Study revealed 58.2% of households are practicing RWH and among them63.2% installed RWH system more than five years ago.About 63% of households are practicing roof top harvesting which is found to be more convenient in terms of cost and space. Strong positive correlation(R^2=0.876, r=0.942) was observed among amount of water harvested and space occupied by RWH system and was statistically significant ($P < 0.05$).Harvested water isfound mainly used for household's chores, flushing toilets and watering the garden. Majority (95.8%) of respondents did not prefer harvested water for drinking due to its poor water quality, high contamination and bad odor and taste.About 73.2% of the respondents decontaminate harvested water before using and filtration (63%) is found to be most common and effective method for decontamination. Despite of challenges like leakages of storages and gutters, about 87.3% of respondents are strongly satisfied with RWH system as it reduced the municipal water supply bill and provides excess water for the sanitation. Furthermore, the trend analysis showed increment of rainfall in the area by 1.21 mm per annum. Study regarding governmental incentives for the installation of RWH system, availability and accessibility of quality products, training on installation and sanitary management of RWH system would help to shed further light in the aspects of RWH.

Keywords: *Hydro-meteorological data,Rainwater, Rainwater harvesting,Sanitation*

Introduction

The availability of safe and reliable source of water is prerequisite for the establishment of stable community(Koju et al. 2014). Demographic factor, economic and cultural factors are major determinants of the availability of water resources. Human's population explosion and environmental degradation in many developing countries leading to the declination of water availability in many countries (Aladenola and Adeboye 2010, Domene and Saurí 2006). Many surface water sources are being degraded by such anthropogenic interferences further exaggeratingthe problems of water scarcity in such areas. Identification of the alternative sources of water would be vital to solve those problems.

Kathmandu valley (KV) is one of the densely populated city of Nepal and is one of the city where the problem of water availability is rampant. The population of KV is expanding with annual growth rate of 4.63%(CBS 2011). Each year the problems related to the water are being escalating rapidly. Rapid population growth along with unplanned population growth, unsustainably water resources consumption, change in land use pattern and poor managerial system have resulted inconvenient supply of water in KV(Udmale et al. 2016).Currently, Water supply system in the KV is managed by the Kathmandu valley Water supply management board and operated by Kathmandu Upatyaka Khanepani Limited (KUKL)(KUKL 2017). KUKL annual report (2020) reported that average demand of drinking water in KV is 470 million litres a day (MLD) whereas supply is about 106 MLD in rainy season and 80MLD in dry season. Recently first phase of Melamchi water supply project has been completed and delivered 170 MLD water in Kathmandu valley. In addition, 340 MLD is proposed to supply through second phase by 2023(Thapa et al. 2018). The devastating flood of June 15, 2021 in Melamchi river has severely damaged the structures of water supply project which interrupted thecurrent water supply and projected water supply has been postponed. Fulfilling the water demand in the KMC has become challenging.Almost all households in Kathmandu depend on groundwater as their major source of water, but with climate change and the modernization in construction of roads and buildings, the land has turned impervious depriving groundwater of its natural recharge.

The demands are being partially fulfilled by collecting the water from nearby sources, extraction of the ground water and other means. The surface water near the valley area are limited while the ground water is declining rapidly. As the mean annual precipitation of the valley range from 1500mm (city area) to 1800 mm (surrounding hills) per annumwith average 97 rainy days in a year(Thapa et al. 2016), Rain Water Harvesting (RWH) could be one of the options to partially fulfil the water demand of KV. RWH techniques has made significant contribution to overcoming water shortage issues and are found effective in both urban and rural areas (Dahal et al. 2010).RWH is the process of collecting rainwater from surfaces on which rain falls, filtering it and storing it for multiple uses (Barron 2009). In 1960, first modern RWH system was installed in Nepal at mission hospital Pokhara.Rainwater is usually of high quality and is safe for human consumption(Dahal et al. 2010). So,RWH could be the alternative to reduce overloads to the water treatment plants, recharging water to aquifers, primarily drinking purpose and secondarily ground water recharge and flushing toilets (Gautam 2017).However, when options for the problems are discussed, proper understanding the perception of the end consumer to use technology is vital for promoting such alternatives.

In context of degradation of groundwater and surface water in both quality and quantity, RWH could be the better alternative to meet the need of water to some extent. So, this study has aimed to address the current RWH practices and its effectiveness on overcoming the water shortage issues.

Materials and Methods

Study Area

The study was conducted in Kathmandu metropolitan city (Figure 1), situated north-western part of Kathmandu valley, the oldest metropolitan city of Nepal. The geographical area covered by KMC is 49 sq km and has a population 975,453(CBS 2011). The city lies at an average altitude of 1,350 meters above ground level. The climate is sub-tropical cool temperate.In general, the annual maximum and minimum temperature is between 27.9^{o}C in May and 2^{o}C in January, respectively.Average annual rainfall is1483.15mmin the interval of 30 years (1990-2019) recorded at Kathmandu airport station.Heavy concentration of precipitation occurs in the June to August. Average humidity in the city is 75%.

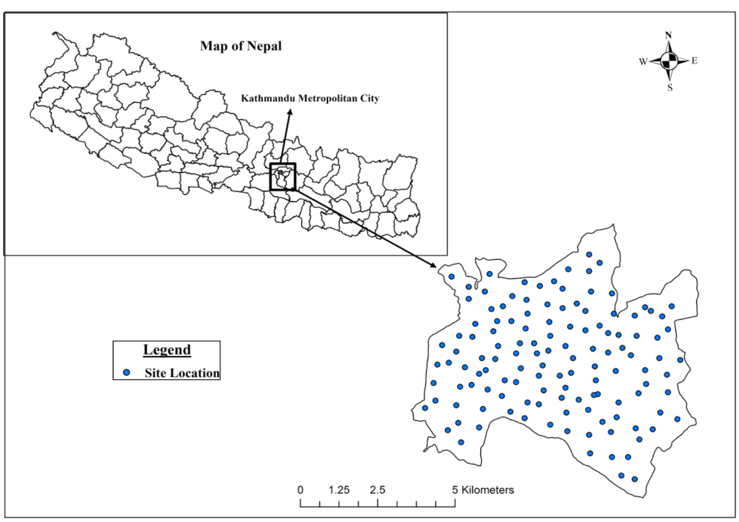


Figure 1 : Map of study area (KMC). Blue dots in the figure are surveyed location.

Data collection

A total of 244 households selected randomly. Prior to the household survey, coordinates were randomly interpolated covering all the 32 wards of KMC using ArcGIS. The real location of the coordinates was then identified and performed survey in the surrounding areas. Verbally consent from the respondents was taken before the survey. A social survey was performedwith the use of semi structured questionnaire for the collection of primary data regarding rainwater harvesting practices, harvesting techniques, its management and effectiveness.Age group of the respondents were ranged from 20-60 years old. Therainfall dataof Kathmandu Airport Station (1030) of interval 30 years (1990-2019) were collected from DHM.

Data analysis

All the data were statistically analyzed through MS Excel 2010. Data were represented in bar graphs and doughnut. Pearson's correlation was performed to analyze relation between space occupied by RWH system and amount of rainwater harvested. Rainfall data of interval 1990 – 2019 were plotted and trend was determined.

Results and Discussion

Annual rainfall pattern analysis

The data obtained from the DHM reveals an increase in the trend ofrainfall pattern (1.21 mm per year) over the period of 30 years which supports the feasibility of RWH inKathmandu (Figure 2).

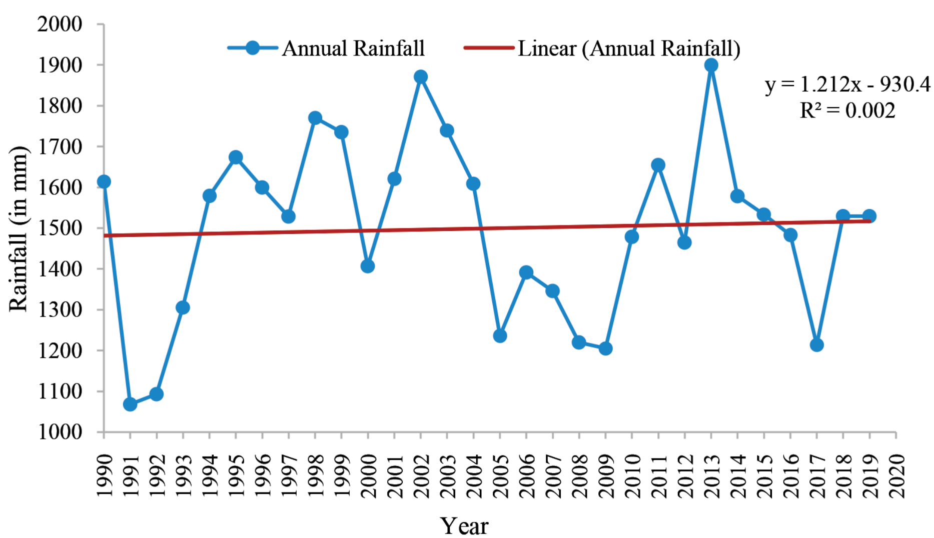


Figure 2: Trend line of annual rainfall recorded at Kathmandu Airport Station

Status of Rainwater Harvesting Practice

The study revealed 63.4% of HHs has installed RWH system survey and practicing more than 5 years ago (Figure 3).

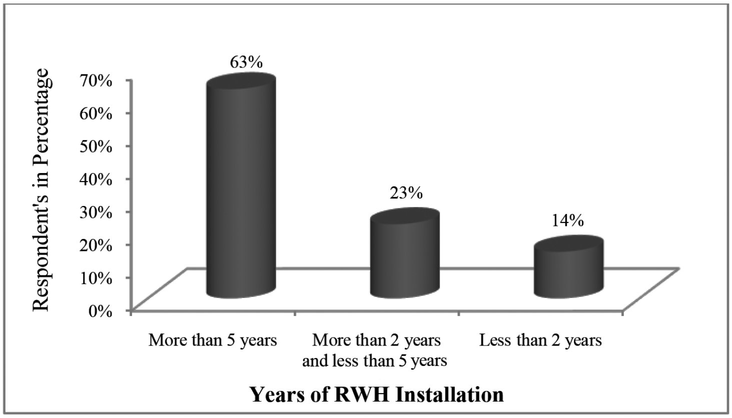


Figure 3:Interval of installation of RWH system

Rainwater Harvesting Techniques

Majority of households (63%) has installed Rooftop harvesting technique followed by direct collection of rainwater (24%), surface runoff harvesting (9%) and only 4% of households practice both rooftop and surface runoff harvesting techniques (Figure 4).The storage of harvesting system was found mainly installed in Terrace (29.5%) followed by Underground storage tank (27.7%), Backyard (21.1%), Front yard (15.5%), nearby field (5.5%) and Balcony (2.8%).

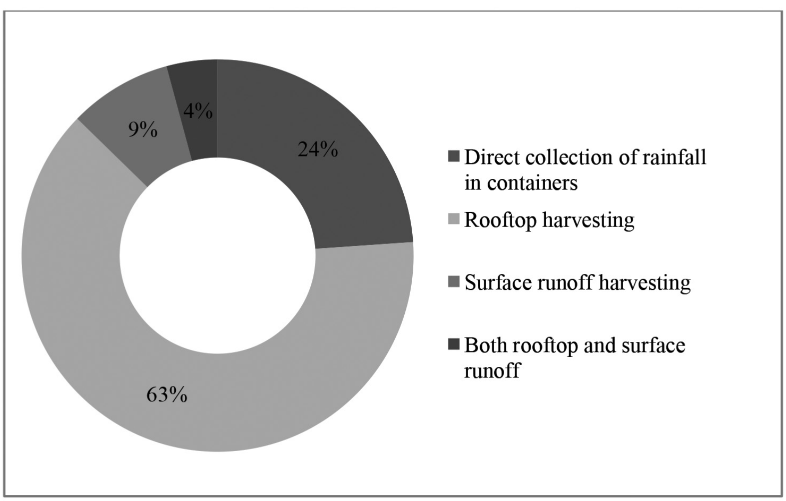


Figure 4: Different techniques used for RWH

RWH supply system

The study revealed mainly five types of harvested water supply system *i.e* water butt, direct-pumped, indirect-gravity, gravity only, indirect-pumped found to be practiced in KMC. These systems have the same purpose but differ in their functioning and the respondents used different types of system based on their convenience. About 59% of the respondents used the water butt technique as it is the most basic form of harvesting rainwater (Figure 5).

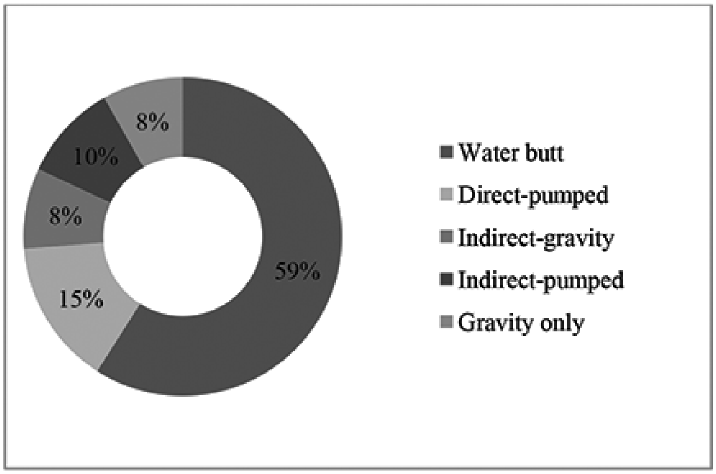


Figure 5: Type of system used for supplying harvested water.

Use of harvested water

Study revealed 74.6% of the households used harvested rainwater for household's chores activities such as cleaning, washing clothes and dishes and mopping the floor (Figure 6). About 59.2% of the households useharvested water for flushing toilets which helps to reduce ground water consumption and promotes sanitation. About 42.3% use harvested water in their gardens for watering the plants and other gardening purposes. Majority (95.8%) of the householdsdon't prefer rainwater for drinking purposes. Poor water quality, bad taste and odour, high contamination are major cause reported for not preferring to drinking purpose. A total of 73.2% of the respondents decontaminated the harvested rainwater before using it. Filtration, chlorination, sedimentation, boiling and solar water disinfection (SODIS) methods are found usually practiced for the decontamination. Among them,media filtration method (63%) is found to be most common decontamination method. Among the households who are using harvested water for drinking purpose, only 5.6% of HHstests the quality of water every season.

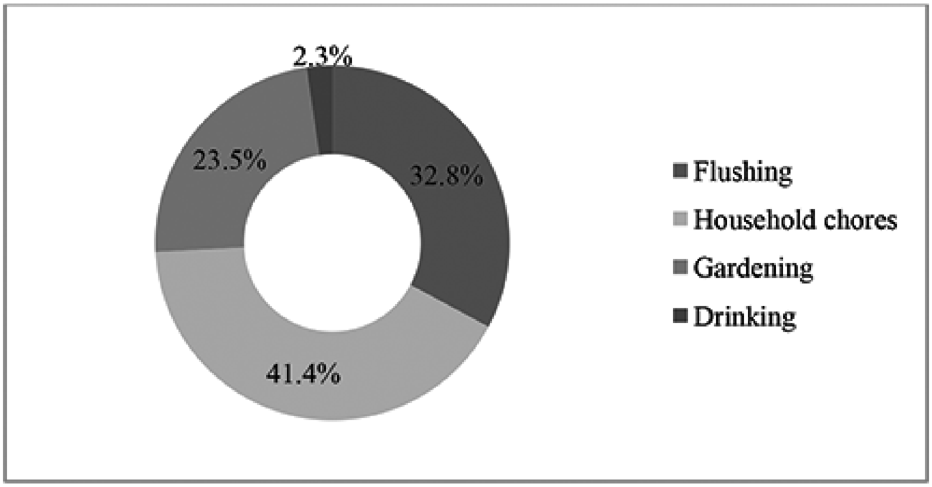


Figure 6: Purpose of use of the harvested water

Space occupied and amount of water harvested

The relation between amount of water harvested and space occupied by the harvesting system was found strongly correlated (R^2=0.876, r=0.942) and is statistical significant ($P<0.05$).Space occupied by harvesting system found ranging from less than 100 sq ft to 600 sq ft. About 27% of the households have installed harvesting system in less than 100 sq ft.

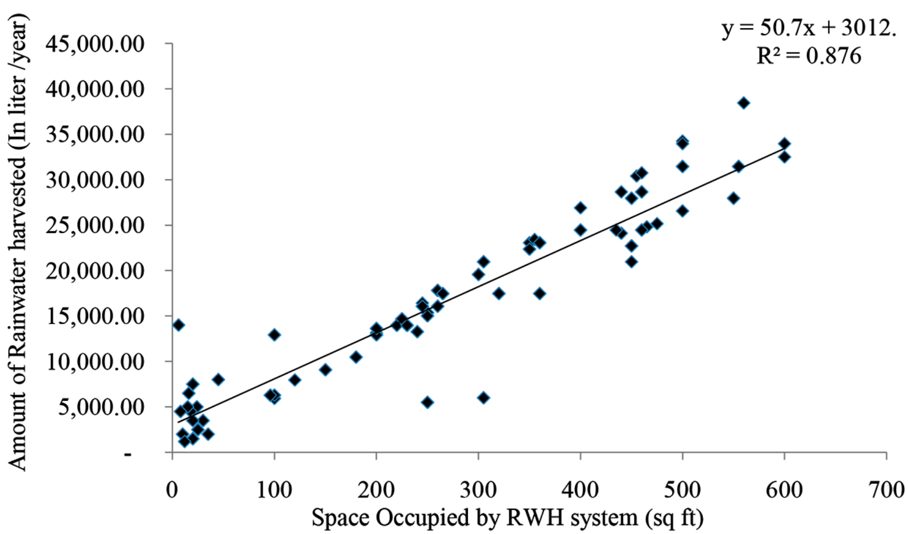


Figure 7: Relation between amount of rainwater harvested and space occupied

Operation and Maintenance

There is no proper timing observed for cleaning of storages and catchment areas in the study area. Four households were found cleaning catchment right before the rainy season. First flush method is not found practicing which is due tonot using harvested water for drinking purpose and no one in the house during the day time to flush the first rain. A total of 22.5% of the respondents reported leakages of storage and gutters are major challenges facing whereas mosquitoes breeding and contamination due to wind and bird faeces are common and simple issues reported.

Benefits and level of satisfaction

Majority of households (87.3%) found to be strongly satisfied and considered RWH as best alternative for fulfilling current water demand. Remaining (12.7%) reported issues like contamination, leakages of gutter and storage and small area for RWH system which makes them not much satisfied but are agreed with fulfilling water demand. About 60% of the respondents agreed with reduction on municipal water supply bill due to RWH system installed.

The results above revealed RWH practices are feasible in terms of its quality and quantity. Low installation and maintenance costand multiple use of harvested water showsits effectiveness towards meeting the water need. High amount of rainwater collected during the monsoon season supports to fulfil current demand of water to some extent (Gautam 2017). The rainfall data (Figure 1) shows increasing trend over the period of 30 years.

Harvested water has multiple uses and varies among the households. During the rainy season people use rainwater for most of their activities in order to save water from other sources. Drinking and cooking require a better water quality, the harvested water needs to be purified and storage should be timely cleaned. Using rainwater for flushing helps to save a lot of groundwater which also promotes sanitation (Pasakhala et al., 2013). Respondents were found to be cleaning and flushing their toilets more often than before after using harvested rainwater as they did not have to pay for rainwater, which shows RWH has also helped in maintaining sanitation.Although the rainwater is of very high quality (Shrestha et al. 2013) fallen leaves, suspended dust particles and rust of the catchment materials are found to be major causes of contamination of harvested water. The study shows that the chances of contamination increase due to presence of leaves, dust particles or microbes or due to rusting of catchment materials.

The capacity of a harvesting system to collect rainwater depends on the area of the roof or catchment area and the amount of precipitation (Udmale et al., 2016), so people also rely on water from other sources during dry seasons. Respondents mainly relied on

KUKL water supply system, Tankers/ Jar water and stone spouts as well.For drinking water, they mostly relied on Jar/bottled water and tap water is mostly used for drinking purpose.

Rainwater harvesting is viewed as a practice that is socially acceptable and environmentally responsible all the while, promoting self-sufficiency (Dahal et al., 2013). The study revealed majorityof the HHs was satisfied with the benefits of access to water for household's chores and support on reducing water bill. Regular cleaning of storage tank and contamination through winds were found RWHpractice hectic and time consuming.RWH is currently practiced all around the world and is suitable alternative for domestic use and irrigation (Liang and Van Dijk 2016) also enhance water security (Christian Amos et al. 2016). Abundance of conventional water sources, climatic conditions, financial and institutional support are some major determinants for the effectiveness of RWH system(Christian Amos et al. 2016). RWH systems are cost effective during installation (Gautam 2017), supports on recharging ground water, irrigation and also reduces urban flooding (Jamali et al. 2020).

Conclusion

RWH techniques being cost effective and requires small area is rapidly adopting by the peoples of KMC. Rainwater, although being purest form, was found mainly usedfor households chores, flushing, gardening and few households found using for drinking. Except drinking purpose, harvested water was not found tested chemically and timely cleaning the storage and gutters.

References

- Aladenola, O.O. and Adeboye, O.B. (2010) Assessing the potential for rainwater harvesting. Water resources management 24(10), 2129-2137.

- Barron, J. (2009) Rainwater harvesting: a lifeline for human well-being, UNEP/ Earthprint.

- CBS (2011) Population & Housing Census 2011.

- Christian Amos, C., Rahman, A. and Mwangi Gathenya, J. (2016) Economic analysis and feasibility of rainwater harvesting systems in urban and peri-urban environments: A review of the global situation with a special focus on Australia and Kenya. Water 8(4), 149.

- Dahal, R., Ban, J., Makaju, S., Shrestha, R.S. and Dwa, N. (2010) Rainwater Harvesting (RWH) in Nepal. Retrieved August 10, 2013.

- Domene, E. and Saurí, D. (2006) Urbanisation and water consumption: Influencing factors in the metropolitan region of Barcelona. Urban Studies 43(9), 1605-1623.

- Gautam, R. (2017) Potential of rainwater harvesting in Nepal: a case study of kathmandu, Norwegian University of Life Sciences, Ås.

- Jamali, B., Bach, P.M. and Deletic, A. (2020) Rainwater harvesting for urban flood management–An integrated modelling framework. Water research 171, 115372.

- Koju, N.K., Prasai, T., Shrestha, S.M. and Raut, P. (2014) Drinking water quality of Kathmandu Valley. Nepal Journal of Science and Technology 15(1), 115-120.

- KUKL (2017) Kathmandu Upatyaka Khanepani Limited: Annual Report, KUKL Kathmandu.

- Liang, X. and Van Dijk, M.P. (2016) Identification of decisive factors determining the continued use of rainwater harvesting systems for agriculture irrigation in Beijing. Water 8(1), 7.

- Shrestha, S., Prasad Pandey, V., Yoneyama, Y., Shrestha, S. and Kazama, F. (2013) An evaluation of rainwater quality in Kathmandu Valley, Nepal. Sustainable Environment Research 23(5).

- Thapa, B.R., Ishidaira, H., Bui, T.H. and Shakya, N.M. (2016) Evaluation of water resources in mountainous region of Kathmandu Valley using high resolution satellite precipitation product. 72(5), I_27-I_33.

- Thapa, B.R., Ishidaira, H., Pandey, V.P., Bhandari, T.M. and Shakya, N.M. (2018) Evaluation of water security in Kathmandu valley before and after water transfer from another basin. Water 10(2), 224.
- Udmale, P., Ishidaira, H., Thapa, B.R. and Shakya, N.M. (2016) The status of domestic water demand: supply deficit in the Kathmandu Valley, Nepal. Water 8(5), 196.

Distribution and Dynamic Behaviors of Landslide in Rangun Khola Watershed of the Western Nepal

Lalit Pathak[1], Krishna Chandra Devkota[2]*
[1]Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal
[2]Global Institute for Interdisciplinary Studies, Kathmandu, Nepal
*Corresponding email: kesandevkota@gmail.com

Abstract

Being a major devastating hazard, the study of landslides in Nepal Himalaya is very essential. For controlling and mitigative measures, understanding the behaviors and distribution of landslides over the temporal and spatial range is indispensable.The current study is carried out in the Rangun Khola watershed of western Nepal which spreads from Mahabharat Range (2,500m) to Dun valley covering an area of 489.39 km^2.Polygon-based landslide inventory within the temporal range of 18 years (2003 to 2020 AD)was prepared by usingtemporal series of Google Earth Pro,Sentinel-2 images, andLandsat images, which were verified during the field visit. The number of landslides and area covered in different spatial units and temporal intervals were analyzed using the Q-GIS. In total, 494 landslides were identified and the area covered by the landslide was 0.47% of the total study area. Landslides in this area are highly dynamic with different activity states and temporal fluctuation. The number of landslides were highest,i.e., 143, in 2005 and the Upper Siwalik region consist of a large number of landslides making them highly prone to landslide events. The presence of thrust and faults was also found to be influencing the landslides and size distribution.The study will be useful for further researches to map susceptibility and hazard and also for policymakers to understand landslide status to reduce the risk.

Keywords: *Landslides, Landslide Activity, Temporal and Spatial Distribution, Rangun Khola*

Introduction

Landslides can occur almost anywhere in the world; it is among the most lethal geological hazards in mountainous regions (Dhakal, 2014). Thousands of lives and the destruction of billions of properties arecaused by the landslide each year globally (Petley et al., 2007).Adverse and weak geological structuresalong with the influence of hydro-meteorological conditions have triggered hazards like landslides(Dhakal, 2015). Landslide is the most commonand major natural hazard in Nepal, as the country is highly vulnerable because of its young and active geology, seismic activity, high rate of weathering, high relief, fragile geology along with steep topography, undercutting of the banks, high intensity rainfalls during monsoon, and so on (Dhital et al., 1991).

The clustering and categorizing of landslides and their activity state is considered as first step towards landslide hazard mitigation.The study of landslides and relatedphenomena is an emerging interdisciplinary field in Nepal, a quite small number of research work has been undertaken so far (Regmi et al., 2012; Devkota et al., 2012). These studies focused mainly to prepare susceptibility and risk maps based on landslide inventory and various intrinsic and extrinsic factors.The study of past and present landslides are guides to future events,i.e., it is likely that landslide will occur where it has occurred in the past, and have similar geological geomorphological and hydrological conditions as they have in the past(Ercanoglu et al., 2004).Broothaerts et al. (2012) studied the spatial patterns of landslide and their relationship with causes and consequences and found the different spatial clusters of landslides with similar characteristics. So the study of landslide characters on the spatial and temporal basis is very useful to judge the landslide dynamics. In this context, efforts should be increased for landslide mapping and landslide susceptibility assessment to understand the relationship between landslide and contributing factors which can be helpful for prediction and prevention of the landslide hazard in the area. As it is well known that, there are spatial differences inlandslidesbased on geology and structures in Nepalese terrain (Bhandari & Dhakal, 2020).

The spatial distribution indicates the number of landslides in different geological formations whereas temporal pattern or dynamic behavior indicates the state of activity of the landslides. The activity can be described and classified based on state as - Active, Reactivated, Suspended, Inactive, Dormant, and Stabilized (Varnes & Cruden, 1996). Landslides that are currently moving which include first-time movements and reactivations are known as active. Inactive landslides are those that last moved more than one annual cycle of seasons ago which can be subdivided as dormant if the causes of movement remain apparent (Hutchinson & Gostelow, 1976). A landslide that is again active after being inactive may be called reactivated. And the landslides that have stopped movement either by natural or artificial measures can be described as stabilized. The study of the state and behavior of landslides can be possible with the temporal inventory of the landslides, which is used in this study.

Rangun Khola watershed in Sudurpaschim Province constituted of Mahabharat range and Siwalik region, that has faced several damages due to landslides. Different sized landslide is observed in this area every year and landslide is the second-ranked disaster in terms of affected family and estimated loss (MoHA, 2019). Apart from large, many small-scale landslides go unreported; losing productive lands unless and until they involve the loss of life and properties or cause the blockage of the road in rural areas of Nepal(Dahal, 2012). Such unreported landslides are very frequent over this study area and damages are severe. This can be minimized through the implementation of prevention and mitigation strategies, which can be achieved through the application of proper landslide mapping.To reduce the present and future risk and to cope with the impact of landslides, the distribution and dynamics along withmapping of landslides should be carried out. Thus, the main objective of this research is to study the distribution and dynamic behaviors of landslidesin Rangun Khola watershed of Sudurpaschim Province, Nepal.

Materials and Methods

Study area

Rangun Khola situated in the Sudurpaschim Province of Nepal; is one of seven watersheds within the Mahakali River Basin. The watershedranges in elevation from 2,500 m in the north, (Mahabharat range), to 258 m along its southernreaches where the watershed drifts into the Mahakali River at Parshuramdham. This watershed covers an area of

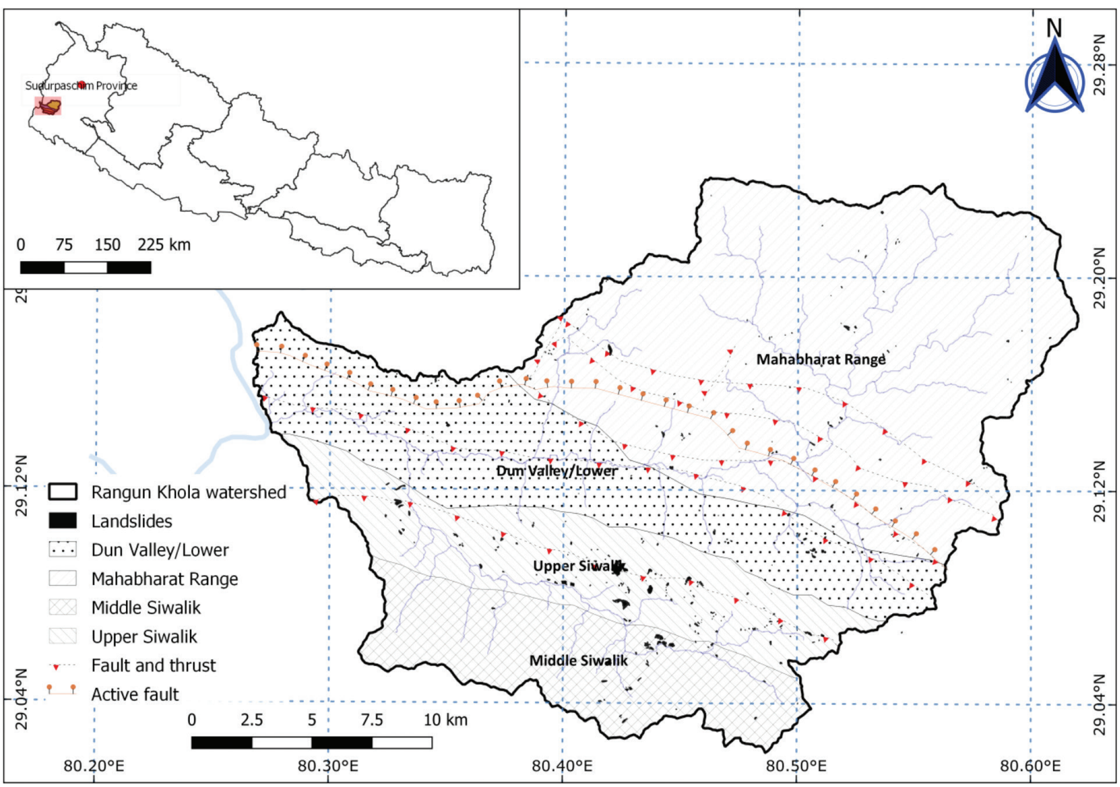


Figure 1: Location of the study area showing landslides distribution geological features (fault and thrust lines adopted from DMG (2020) and active fault adopted from Dhital (2015).

489.39km^2 and is fed by many tributaries within the Siwalik zones that accumulate into the Rangun Khola, which is the main drainage channel for the watershed. The level of the water varies significantly and water-induced disasters like floods, landslides, river cutting, and sand deposition are frequent over the area during the monsoon. According to census 2011, about 53,109 people inhibit within this watershed.The annual average rainfall in the watershed is 1,346.6 mm and the annual temperature ranges between 10°C to 25°C, and (DHM, 2017).The geology of the watershed is comprised of Precambrian augend and banded gneiss and various mixtures of mica-schist and phyllite. An active fault passes close to the main boundary thrust and runs through Budar, Alital, and Kalena (Dhital, 2015). This existing geology and topography make this area prone to landslide hazards. Several historical and present landslides are prevalent in this area. Thus the study of landslide and their distribution and dynamics is necessary for this area.

Data and Methods

For this study,polygon-based spatio temporal Landslide Inventory Map (LIM) was developedfrom 2003 to 2020 AD based on both the desk study. Primarily Google Earth Pro historical imagery was utilized and in case of data deficient and blurred images, Sentinel-2, andLandsat images were used. Similarly, different published and unpublished reports were utilized for verification of the identified landslides in the area. Based on this inventory and repeated field visit the distribution and dynamic behavior of landslides were studied. Preliminary field visit of one week was carried in February, 2020 for identification of landslide prone areas, and after the preparation of inventory a next field visit was conducted in June 2020 for 20 days in order to characterize the landslides.

Distribution and Dynamics of Landslide

The distribution and dynamics of the landslide in this study stand for the spatial distribution of landslides in different lithological zones, the temporal distribution of landslides from 2003 to 2020 the size of the landslides, and state of activity. The classification of landslides was carried out within five years intervals, for example landslides before 2005 were counted and classified in 2005. The classification of activity classes is adopted from Varnes & Cruden(1996) and Bhandari & Dhakal (2020) as classified into the following five classes (Table 1).

Table 1: Landslide classification based on its activities

Name	Activity Class
New (N)	Landslides that have occurred in the last 36 months
Active(A)	The landslide that has been moving every year/Movement has occurred in the last 12 months

Inactive(I)	No movements haveoccurred forthree years and haveno prior probability to reactivate shortly
Reactivated (R)	Landslide reoccurred in the inactive or stabilized landslide
Stabilized(S)	The landslide mitigated naturally or structurally and seems stable at present

In terms of size, landslides were classified into five class namely very small, small, medium large and very large, which were proposed on the basis of logarithmic scale. In the present study size classes were adopted from Bhandari and Dhakal (2020) as described in Table 2.

Table 2: Classes of landslide based on area

SN	Area (m^2)	Size Class
1	<100	Very small
2	100-1000	Small
3	1000-10,000	Medium
4	10,000-100,000	Large
5	100,000-1,000,000	Very large

The study area is composed of four distinct geological units Mahabharat range, Upper Siwalik, Middle Siwalik, and Dun Valley (Hagen, 1969; Dhital, 2015). Above activity class and size of the landslide as behavior is classified and their spatial distribution was studied based on geological formation.

Results and Discussion

Landslide inventory

In the study area total of 494 landslides were identified from 2003 to 2020 based on satellite images and field verification. The size of the individual landslide was found in the range of 68.21 m^2-149,120.10 m^2, with an average size of 4,677.35 m^2, which eventually covers the area of 2,301,058.62 m^2. The total area covered bya landslide is about 0.47% of the total study area.The highest number of landslide events found to occur in 2005 whereas the area covered by the landslide is higher in 2020.The identified landslide wasalso classified in different five classes based upon size namely very small, small, medium, large, and very large based on area. The frequency of the small and medium-sized landslide having an area between 10^2-10^3 m^2 found to be dominant in the study area as shown in Figure 2. The medium and small-sized landslide covered 38% and 50% of the total landslide by number and though the percentage of landslides having a large size is 12% but occupies significant in terms of the area.

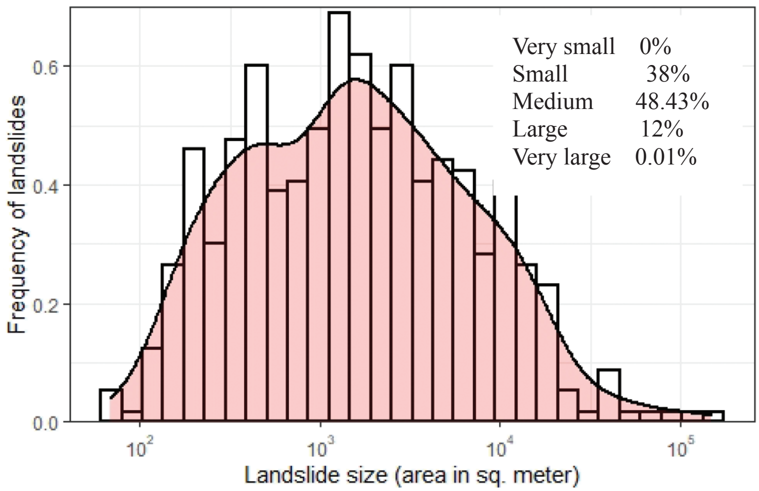


Figure 2: Frequency of different sized landslide.

The elevation ranges from 258 to2,500 m within a very small area and has a higher slope gradient up to 77 degree. Along with the sedimentary rock this caused slope instability and due to which various slope movements like rockfall rock flow, rock slides, and complex types (Varnes & Cruden, 1996) were observed in the study area.The distribution of the small landslides in the study area is due to the fragile nature of the Siwalik region, whereas the occurrence of medium and large sized landslides is due to the presence of active fault that passes close to the main boundary thrust and runs through Budar, Alital, and Kalena. In the south of this active fault, Budar thrust delimits the Siwaliks from the Mahabharat Range. The higher frequency of the small and medium-sized landslides in this study area is a similar result to that of (Bhandari & Dhakal 2020). The densities of the landslide were found higher in the vicinity of these faults and thrust. This shows that the landslide mobility in the study area is greatly affected by lithology along with terrain height and slope. Currently, there are two very large-sized landslides found to be active and the morphology shows the evolution of the landscape found to be greatly influenced by landslide events. As concluded by Fort et al. (2009), landslide events may influence landscape morphology and evolution for thousands of years.

Distribution of Landslides

The spatial distribution of the landslide was studied based on geological formation. The area is composed of four distinct geological units Mahabharat range, Upper Siwalik, Middle Siwalik, and Dun Valley (Hagen, 1969; Dhital, 2015). The spatial distribution of the different size classes of the landslide is presented in Figure 3.

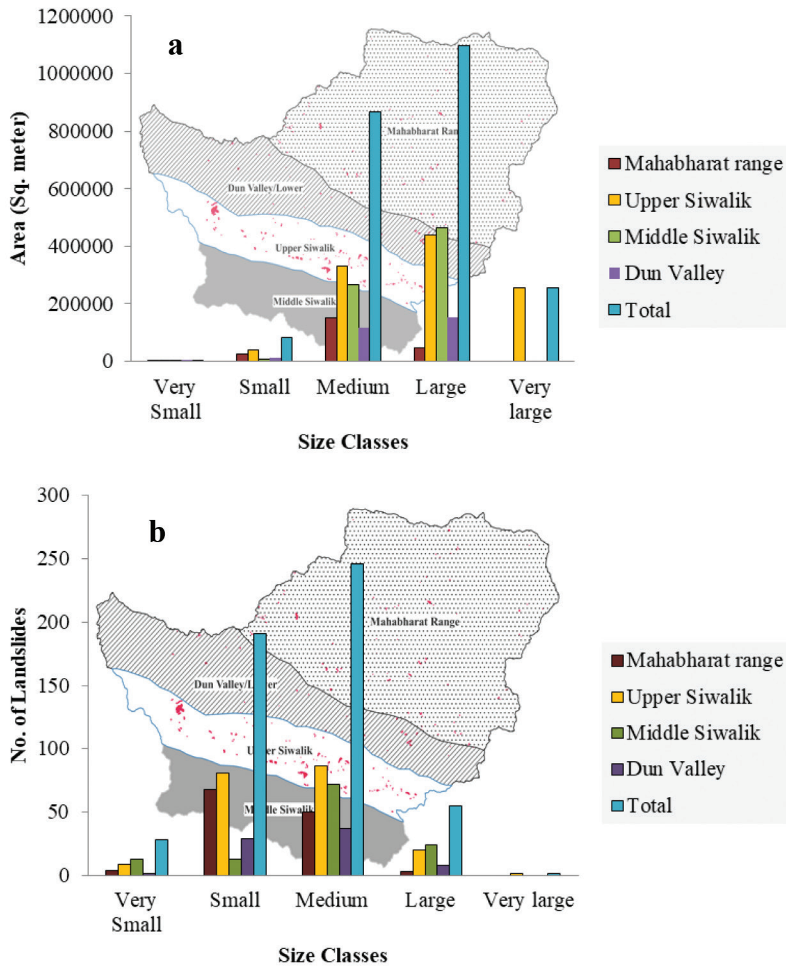


Figure 3: Distribution of landslide in different geological units a) area of landslides and b) number of landslides

The spatial configuration is based upon the number of landslides present inthe study area Upper Siwalik > Mahabharat Range > Middle Siwalik >Dun Valley with 190, 121, 109, and 74 landslide events, respectively. Spatially, there is no significant difference in the size-frequency of the landslides. In the Upper Siwalik, Middle Siwalik, and Dun Valley medium-sized landslides are dominant whereas in the Mahabharat Range,small-sized landslides are more frequent (Figure 4b). There are only two landslides identified having a very large size in the Upper Siwalik region. Upper Siwalik region is in the highest rank (1,062,230.16 m2) in terms of area covered by the landslides and followed by Middle Siwalik (738,325.56m2). Though the number of landslides in the Mahabharat falls in the second-highest rank, the area covered by them is lowest among all four regions due to a higher number of small landslides. From this analysis,Upper Siwalik can be identified as a highly potential region for landslide occurrence in the Rangun Khola watershed.

The temporal distribution of the size-based class and number of landslides was analyzed from 2005 to 20120 AD (Figure 5a). The annual frequency of the landslide was found to be varying significantly. As it is very difficult to differentiate each year event for active landslides, and to examine the exact number of events,five-year interval was considered. The numbers of landslides in 2005 were 143 covering the area of 557,877.19 m^2, but, there was a significant decline in the numbers between 2005 and 2010 and reached 103, covering 521,832.08 m^2 area (Figure 5b). Then the number of landslides was in increasing trend and extended up to 112 and 136 in between 2015 and 2020, respectively.

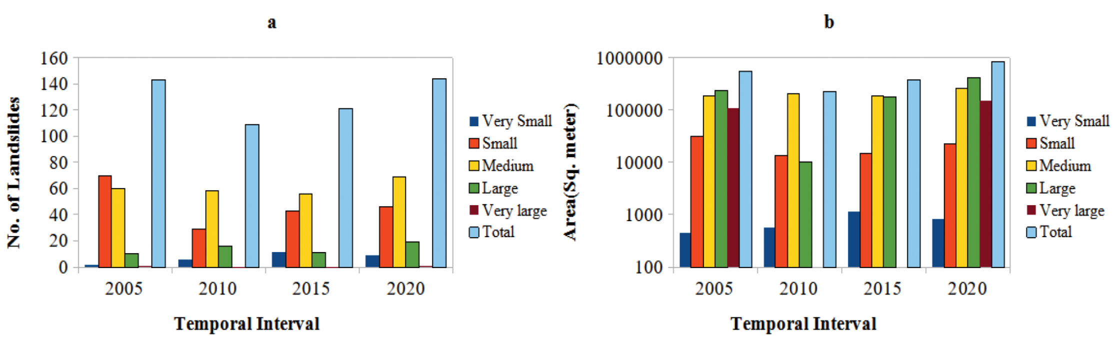
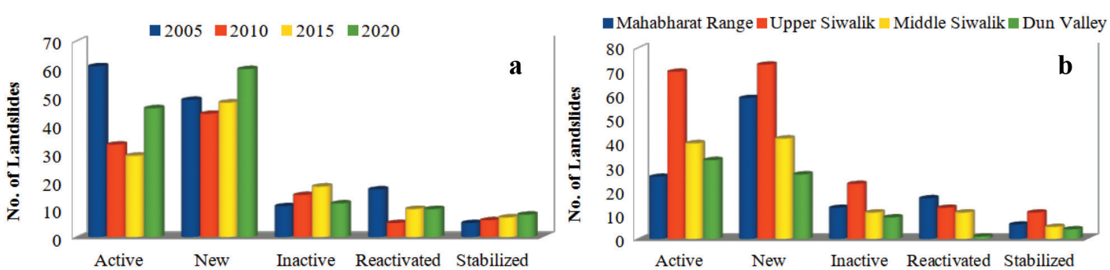


Figure 4: Temporal distribution of landslide, a) number of landslides and b) area of landslides

The number of small-sized landslides was found to be in similar trend as that of the total number of landslides. But the number of medium and large-sized landslides which were dominant of all was in a linear trend. Overall, there were two very large-sized landslides observed, one before 2005 and another during the 2015 to 2020 interval. The distribution of the landslides size shows was not found to be uniform between these geological units. Medium to large scale landslides is commonly found in higher densities temporally and spatially. The trend of the result is similar for temporal intervals. The Mahabharat Range alone covers 51 % of the study area but the number of landslides area is lower than that of Upper and Middle Siwalik and Dun valley (consist of 49% of the area). In the Mahabharat Range, new landslides were dominant, but overall landslides are dominant in the Upper Siwalik region, could be due to Budar thrust and an active fault through Alital, living behind several sag ponds and lakes in its depressions (Dhital, 2015). In the past studies Middle Siwalik was observed as highly prone to landslides in the similar terrain (TU-CDES, 2016; Bhandari & Dhakal, 2019; Bhandari & Dhakal, 2020).

State of activity

The inventories of the identified landslides were classified according to their activity classes in temporal and spatial units.Overall, the area covered by new landslides is about (41%), followed by an active landslide (36%), reactivated landslide (10%), inactive (7%), and stabilized (6%). The number of the landslides classified according to activity class isplotted in a different time interval and geological areas are presented in Figures 8a and b. The number of the landslides is in the order of New> Active > Inactive> Reactivated > Stabilized with 201, 169, 56, 42, 26 number, respectively. The highest numbers of active landslides were observed in 2005 whereas new landslides were highest in 2020. The numbers of the stabilized landslides werein the increasing trend whereas the numbers of other classes found to be fluctuating over time. All classes of landslides were found to be dominant in the Upper Siwalik followed by the Mahabharat Range and Middle Siwalik region. In the Mahabharat Range, new landslides were found to be more dominant, but overall, the numbers of reactivated landslides were highest in the Mahabharat Range than other geological units. The stabilized landslides were observed in the lowest count in all geological units.



The distribution and activity of the landslides were found to be significantly varying spatially and temporally. This is mainly caused by the existing geological setting, types, and weathering status of rocks and morphology. The Mahabharat Range consists of Lesser and Higher Himalayan rocks having higher grade metamorphism steadily increases upwards. At first, gray biotite schists, quartzites, and feldspathic schists are seen, and then there are zones of schist with some tiny garnets (Dhital, 2015). Upper Siwalik, which most prone area for landslide in this region is characterized by coarse, dissected, and subdued topography. Ephemeral streams can be observed running through them produce a huge amount of coarse sediment. Upper Siwaliks are interstratified with sands and a subordinate amount of clay. The sediments consist of poorly graded materials, including pebbles, cobbles, and boulders, derived from the Lesser Himalaya and the Higher Himalaya (Dhital, 2015).

Conclusion

The study concludes that there are clear spatial differences in the distribution of landslides based on the geological units and temporal intervals. The total area covered by a landslide is 0.47% of the total area.The new and active landslides are commonly observed. The landslides having a size distribution between 10,000 m^2 and 100,000 m^2 are characteristic ofthe study area.Along with the lithology, the presence of thrust and faults was also found to be influencing the landslides.The Upper Siwalik region consists of a large number of landslides making them highly prone to landslide events. The total numbers of landslides fluctuated yearly and the highest, i.e., 143, landslides were in 2005. Some of the areas found to be dominant with frequent landslides and characterized as active landslide zone. Frequent landslide zones should be avoided or require further engineering geological and geotechnical considerations. Thus, to protect life and propertyfrom these landslides, mapping can be used as the basic tool to understand landslides. Also,further study of landslides along with land management andplanning future construction is immediate need in this area.

Acknowledgments

This research was carried out for the fulfillment of a M.Sc. degree from Central Department of Environmental Science, Institute of Science and Technology, Tribhuvan University, Nepal. The authors are obliged to different reviewers for their contribution and the Department of Environment, MoFE, Nepal for granting this research.

References

- Bhandari, B. P., & Dhakal, S. (2020). Spatio-temporal dynamics of landslides in the sedimentary terrain: a case of Siwalik zone of Babai watershed, Nepal. *SN Applied Sciences*, *2*, 1-17.

- Broothaerts, N., Kissi, E., Poesen, J., Van Rompaey, A., Getahun, K., Van Ranst, E., & Diels, J. (2012). Spatial patterns, causes and consequences of landslides in the Gilgel Gibe catchment, SW Ethiopia. *Catena*, *97*, 127-136.

- CBS. (2011). Statistical year book of Nepal. *Central Bureau of Statistics*.

- Dahal, R. K. (2012). Rainfall-induced Landslides in Nepal. *International Journal of Erosion Control Engineering*, *5*(1), 1–8. https://doi.org/10.13101/ijece.5.1

- DHM (Department of Hydrology and Metereology). (2017) Climatic records of Nepal. Department of Hydrology and Meteorology, Kathmandu

- DMG (Department of Mines and Geology). (2020). Geological Map of Sudurpaschim Province, Scale: 1:350,000, Department of Mines and Geology, Government of Nepal, Kathmandu

- Devkota, K. C., Regmi, A. D., Pourghasemi, H. R., Yoshida, K., Pradhan, B., Ryu, I. C., & Althuwaynee, O. F. (2012). Landslide susceptibility mapping using certainty factor, index of entropy and logistic regression models in GIS and their comparison at Mugling–Narayanghat road section in Nepal Himalaya. *Natural hazards*, *65*(1), 135-165.

- Dhakal, S. (2015). Evolution of geomorphologic hazards in Hindu Kush Himalaya. In *Mountain hazards and disaster risk reduction* (pp. 53-72). Springer, Tokyo.

- Dhital, M. R. (2015). *Geology of the Nepal Himalaya: regional perspective of the classic collided orogen*. Springer.

- Dhital, M. R., Upreti, B. N., Dangol, V., Bhandari, A. N., & Bhattarai, T. N. (1991). Geological engineering methods applied in mountain road survey: an example from Baitadi-Darchula Road Project (Nepal). *J Nepal Geol Soc*, *7*, 49-67.

- Ercanoglu, M. U. R. A. T., Gokceoglu, C. A. N. D. A. N., & Van Asch, T. W. (2004). Landslide susceptibility zoning north of Yenice (NW Turkey) by multivariate statistical techniques. *Natural Hazards*, *32*, 1-23.

- Fort, M., Cossart, É., Deline, P., Dzikowski, M., Nicoud, G., Ravanel, L., ... & Wassmer, P. (2009). *Geomorphic impacts of large and rapid mass movements: a review,* 15,47-64.

- Hagen, T. (1969). Report on the Geological survey of Nepal, Vol. 1: preliminary reconnaissance. *Denkschriften der Schweizerischen Naturforschenden Gesellschaft Memoires de la Societe Helvetique des Sciences Naturelles*, *84*, 185.

- Hutchinson, J. N., & Gostelow, T. P. (1976). The development of an abandoned cliff in London Clay at Hadleigh, Essex. *Philosophical Transactions for the Royal Society of London. Series A, Mathematical and Physical Sciences*, 557-604.

- MoHA (2019). Nepal disaster report 2017. Kathmandu: Government of Nepal, Ministry of Home Affairs.

- Petley, D. N., Dunning, S. A., & Rosser, N. J. (2007). The analysis of global landslide risk through the creation of a database of worldwide landslide fatalities. In *Landslide risk management* (pp. 377-384). CRC Press.

- Regmi, A. D., Devkota, K. C., Yoshida, K., Pradhan, B., Pourghasemi, H. R., Kumamoto, T., & Akgun, A. (2014). Application of frequency ratio, statistical index, and weights-of-evidence models and their comparison in landslide susceptibility mapping in Central Nepal Himalaya. *Arabian Journal of Geosciences*, *7*, 725–742. https://doi.org/10.1007/s12517-012-0807-z

- TU-CDES (2016) Landslide Inventory Characterization and Engineering Design for Mitigation Works of Chure Area in Ten Districts. Central Department of Environmental Science, Tribhuvan University and Government of Nepal, President. Chure-Tarai Madhesh Conservation Development Board, Kathmandu

- Varnes, D. J., & Cruden, D. M. (1996). Landslide types and processes. *Landslides: investigation and mitigation, Transportation Research Board special report*, *247*.

Richness and Impact of Invasive Alien Species Plant in Trees of Shivapuri Nagarjun National Park, Central Nepal

Rubina Karki[1], Sweta Dixit[1], Satyam Kumar Chaudhari[2], Man Kumar Dhamala[1,2,4], Sijar Bhatta[1]
Dipak Khadka[3, 4*]
[1]Golden Gate International College, Tribhuvan University Kathmandu Nepal
[2]Central Department of Environmental Science, Tribhuvan University, Kirtipur Nepal
[3]Guangdong Key Laboratory for Innovative Development and Utilization of Forest Plant Germplasm, College of Forestry and Landscape Architecture, South China Agricultural University, Guangzhou, China
[4]Environment Protection and Study Center (ENPROSC), Kathmandu, Nepal
*Corresponding email: d.khadka@goldengate.edu.np

Abstract

The effect of invasive species on biodiversity is a major issue of world. This study was conducted at the Shivapuri Nagarjun National Park, this study assessed the invasive species status factor associated with it and their impact on seedling and sapling of trees. Modified Whittaker Nested sampling stratifies was adopted for vegetation sampling. A total of 15 plots were taken with 195 subplots between 1409 m to 2140 m. altitudinal ranges. A total of 32 tree species and nine invasive species were recorded from the studied sites. The pine forest was having significantly (W = 3, p = 0.03) more coverage of invasive species than mixed forest, the coverage of invasive species was also significantly (W = 50, p = 0.009)more with more invasive species than plot with single invasive types. Beside this coverage was also affected by canopy cover, trampling and altitude but not significantly different. The invasive species have impact on numbers of seedling, sapling and their diversity species coverage. We recommend removing these invasive species.

Keywords: *Invasion, Native, Park, Plant, Trampling*

Introduction

An invasive species is a plant, fungus, or animal species that is not native to an exclusive area or location and has the propensity to cover a range that could cause damage to the environment, human economy, or human health (Colautti & MacIsaac, 2004). Invasive species can successively harm the natural resources in an ecosystem as well as threaten anthropogenic use of these resources (Fei, Phillips, & Shouse, 2014). They are a topic of controversy, as it is often confusing to understand whether they are a boon or a bane (Rai et al., 2012). Habitats high in native species richness often have high invasive species richness (Peng et al., 2019).

The introduction of invasive alien species (IAS) occurs through anthropogenic means whereas the dispersal of native invasive species may occur due to natural processes or human activities (Shrestha, 2016). After being introduced to an environment, the establishment and colonization of invasive species largely depend upon the availability of resources and human influence (Shrestha, 2016). An environment with unused resources makes the place more prone to invasion (Davis et al., 2000) and anthropogenic movement increases the propagule pressure of invasive species (Simberloff, 2009).

IAS is one of the crucial direct drivers of loss of biodiversity and change in ecosystem services (Brunel et al., 2013; Chaudhari et al., 2021). The extension of IAS is a topic of global concern since it could impoverish native biodiversity and impact ecosystems and their life forms and habitats from aquatic to wetlands, to grasslands, and forested areas as well. In recent times, the negative impacts of invasive species on resident communities are gaining more attention and also their mechanisms (Schirmel et al., 2016); (Wardle & Peltzer, 2017). The impacts of biological invasion in the context of ecology and evolution could eventually lead to the extinction of species, ecosystem process modification such as changes in nutrient cycling, fire regimes, and even alteration in hydrology (Evans et al., 2016). A strong linkage between invasion and various factors such as global warming and increment in the human population is predicted to increase the threats of IAS (Simberloff et al., 2013; Spear et al., 2013).

The problems of invasive species are common to the developed as well as developing countries. However, their impacts are seen to be greater in developing countries like Nepal because of inadequate resources and expertise for their management (Shrestha, 2016). In the context of Nepal, invasive and alien species are profoundly common and expanding rapidly in natural as well as anthropogenic landscape, and such systems even though are noted to be highly impacted economically, ecologically as well as evolutionarily, they have not been yet assessed elaborately. (Shrestha,2016) A total of 26 species of naturalized plants are considered as invasive and most problematic species (Tiwari et al., 2005; Shrestha et al., 2017), introduced from South America, Mexico, and tropical America. Similarly, Shrestha (2016) studied IAPS like *Lantana camara, Chromolaena odorata, Ageratina. adenophora, Mikania micrantha, Hyptis suaveolens* and projected that these invasive plant species have severely impacted the lower Terai, Siwalik, and Mid Hill regions of Nepal with serious repercussions to growth and productivity of ecosystem diversity.

The mid-hills of Nepal containing the temperate region (2000-3000m) is dominated by evergreen, broad-leaved, and mixed forests. Some of the species present in this region are *Persea duthiei, Phoebe lanceolata, Cinnamomum tamala, Lindera nacusua, Quercus lamellosa Quercus, Quercus semecarpifolia, Picea smithiana, Abies pindrow, Cupressus torulosa, Cedrus deodara*, deciduous species of *Aesculus-Juglans-Acer,* and

Magnolia-Acer-Osmanthus. (Tiwari et al., 2005) These forest ecosystems are being severely impacted by invasive species.

A prerequisite for characterizing invasibility is dependent upon the level of the biodiversity and disturbances of the ecosystems (Catford et al., 2012). Therefore, ecosystems with a history of recurrent disturbances (such as trampling and grazing) should consist of species with adaptations to frequent disturbances (Souther et al., 2019). The impacts of invasive species on ecosystems and their services are also affected by interactions with disturbance indices such as fire, weather, trampling, and other disturbances. Disturbance and invasion could be negatively or positively correlated(Bulleri et al., 2016).

Invasive species vastly affect the forest ecosystem which could ultimately affect the economy and wellbeing of the local people. Biological Invasion is not only a malady to the environment, but in the anthropocentric views, it hampers the livelihood of the local people. Taking into account the fact that limited studies related to invasive species have been done at the Shivapuri Nagarjun National Park, this study had found the invasive species status factor associated with it and their impact on seedling and sapling of trees.

Materials and Methods

Study Area

Shivapuri Nagarjun National Park (SNNP) covers 159 sq. km and is located between 27°45' to 27°52' N and 85°15' to 85°30' E with two isolated island forests viz. Shivapuri and Nagarjun in the central part of Nepal. The Government of Nepal has declared the Shivapuri Watershed and Wildlife Reserve as a National Park in 2002 and the Nagarjun forest area has been annexed in 2009 AD (SNNP, 2010). The national park extends to Sindhupalchowk, Dhading, and Nuwakot districts (Bhuju, Sakya, Basnet, & Shrestha, 2007) and is the subject of interest because of its high biodiversity, species richness, along with invasive species affecting the native species in the national park (Shrestha S., 2014). The park stretches about 20-24 km from east to west and about 8-10 km from north to south. The park boundary is well demarcated with a 111 km long wall around the park. The boundary walls run along/between several villages (formerly Village Development Committees, VDCs) that include Talakhu, Chhap, Likhu, Samundra Devi, Sikre, Sunkhani, and Thanapati of Nuwakot district in the north and Bajrayogini, Baluwa, Chapali, Bhadrakali, Gagalphedi, Jhor Mahankal, Nayapati, Sangla, Sundarijal, and Bishnu Budhanilkantha of Kathmandu district in the south. It is a protected area that falls entirely within the middle mountain range of Nepal. The name of the park is also considered to derive from the ancient name Shiphuchd representing the holy peak of woods (ShNP Management Plan, 2004). SNNP is linked by four major road-networks from the valley (Kathmandu to Budhanilkantha, Tokha, Kakani, and Sundarijal) (SNNP, 2010). The study area (Figure 1) in this research started from the Sundarijal Entrance to Chisapani Village from an altitude of 1400 masl to 2140 m asl.

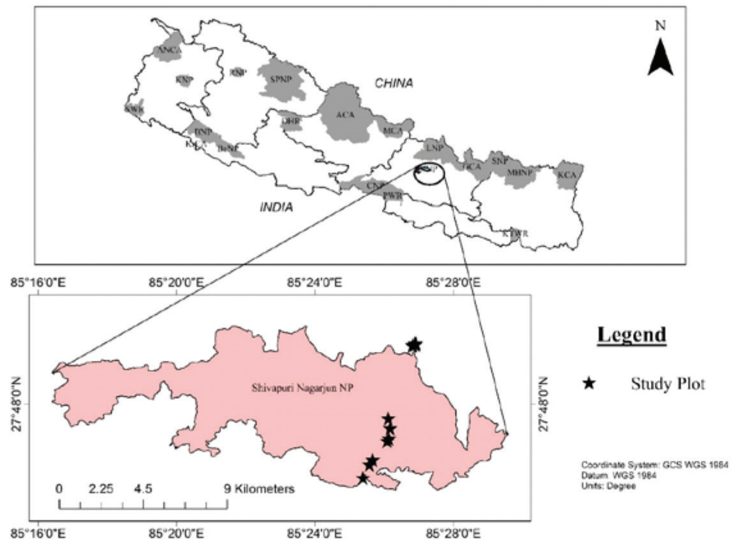


Figure 1: Study area map showing the Shivapuri Nagarjun National Park.

Field Sampling

We applied the modified Whittaker nested vegetation sampling method for the study. The Modified-Whittaker plot design is a vegetation sampling design that can be used for assessing plant communities at multiple scales (Stohlgren et al., 1995). A total of 15 plots were taken with 195 subplots. Sampling was carried out between the altitudinal ranges of 1409m to 2140m. Each plot was measured 20m by 50m (1000m^2) and contained nested subplots of three different sizes. A 5m by 20m (100 m^2) subplot was placed in the plot's center, and two 2m by 5m (10 m^2) subplots were placed in opposite corners of the plot. There was a total of ten 0.5m by 2m (1 m^2) subplots. Six were arranged systematically inside and adjacent to the 1,000 m^2 plot perimeter and four were arranged systematically outside and adjacent to the 100 m^2 subplot perimeter. At each ground sampling point, a Modified-Whittaker nested vegetation sampling plot was established. In the 1000m^2 plot, the number of individuals of each species in the tree stage was counted and the diameter at breast height (DBH, measured at 137cm above the ground) was measured. Individuals of tree species were divided into three growth stages: trees (DBH>9 inches), saplings (DBH= 1-4.9 inches), and seedling (DBH< 1inch) (Interior West Forest Inventory and Analysis (IWFIA Program, 2001). Species diversity of each plot was calculated. The sapling count was recorded in the 100-m^2 subplot to determine the sapling diversity for each plot. Likewise, in the two 10-m^2 subplots, coverage of the invasive species and invasive species richness was recorded.

Trampling type disturbance

The trampling percentage was visually estimated, the method adapted from Marques et al. (2001). The disturbance index value was classified according to the class of trampling intensity.

Table 1 Disturbance Index Values for Trampling

SN	Trampling (%)	Disturbance index value	Disturbance intensity
1	0	0	Low
2	0-30	1	Medium
3	>31	2	High

Data Analysis

Species Diversity Index (H')

The Shannon index Shannon & Weaver (1949) was employed for the estimation of species diversity; seedling and sapling diversity.

Where,

H' = Species Diversity Index
Pi = proportion of the species; Pi
N = total number of individuals of species
ni = importance value of each species

Percentage coverage of Invasive Species

The percentage coverage of invasive species was calculated by using a direct estimate of cover (Daubenmire, 1959) which is given by the following formula:We made boxplot and did statistical test using R core 2018. To see the invasive species coverage relationship with forest type, invasive species richness, and altitudinal range Wilcox test was performed. For invasive species coverage with extent of trampling (low, medium and high) and canopy cover classes Kruskal wallis test was performed.

Results and Discussion

Invasive Species

We recorded nine invasive species, Eupatorium *adenophora* L. *(72.05%)*, *Galinsoga parviflora* Ruiz & Pav. *(8.06%), Xanthium strumarium* L. *(7.87%), Lantana camara* L. *(7.73%), Oxalis latifolia Kunth (1.88%), Amaranthus spinosus* L. *(0.93). Solanum* *viarum (1.16%), Ageratum conyzoides* L. (0.31%) and *Bidens Pilosa* L. (0.02%) (Figure 2), along with 32 tree species; the dominated tree species were *Pinus roxburghii*, *Schima wallichii, Fraxinus floribunda, Juniperus* sp. and *Pyrus pashia.*

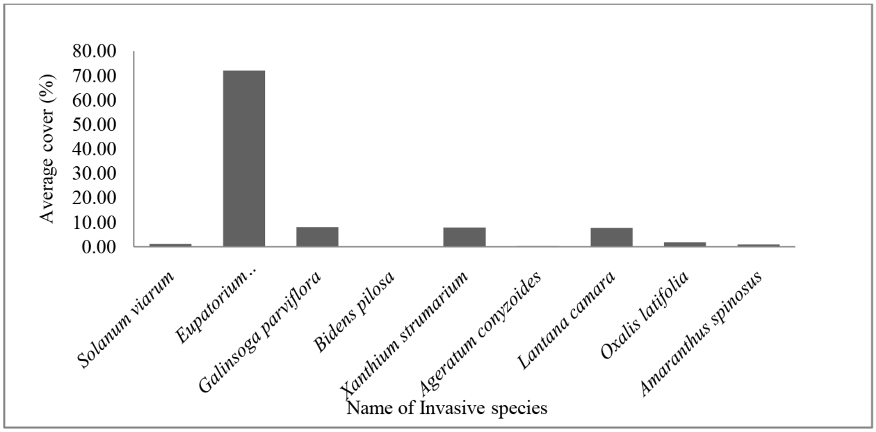


Figure 2: Invasive plant species coverage in SNP.

Invasive species Cover and Covariant

The invasive species coverage was dependent on different covariant (Figure 3). The mean invasive species cover was 6.67± 1.77 (S.E) with the range 0 to 22.604. The pine had significantly ($W = 3$, $p= 0.03$) more coverage of invasive plant species than mixed forest. The plots with a single type of invasive species had significantly ($W = 50$, $p = 0.009$) low coverage of invasive species than more type of invasive species (2 to 6). High trampling was supporting invasive species but not significantly ($\chi^2= 4.381$, df = 2, $p= 0.112$) different, with the canopy cover 40-50 the median invasive species coverage was more but not significantly ($\chi^2 = 2.2552$, df = 2, $p = 0.323$) different with canopy coverage classes. The invasive coverage was also not significantly different ($W = 31$, $p= 0.778$) at above and below 2000m altitude although the invasive species was more above 2000m.

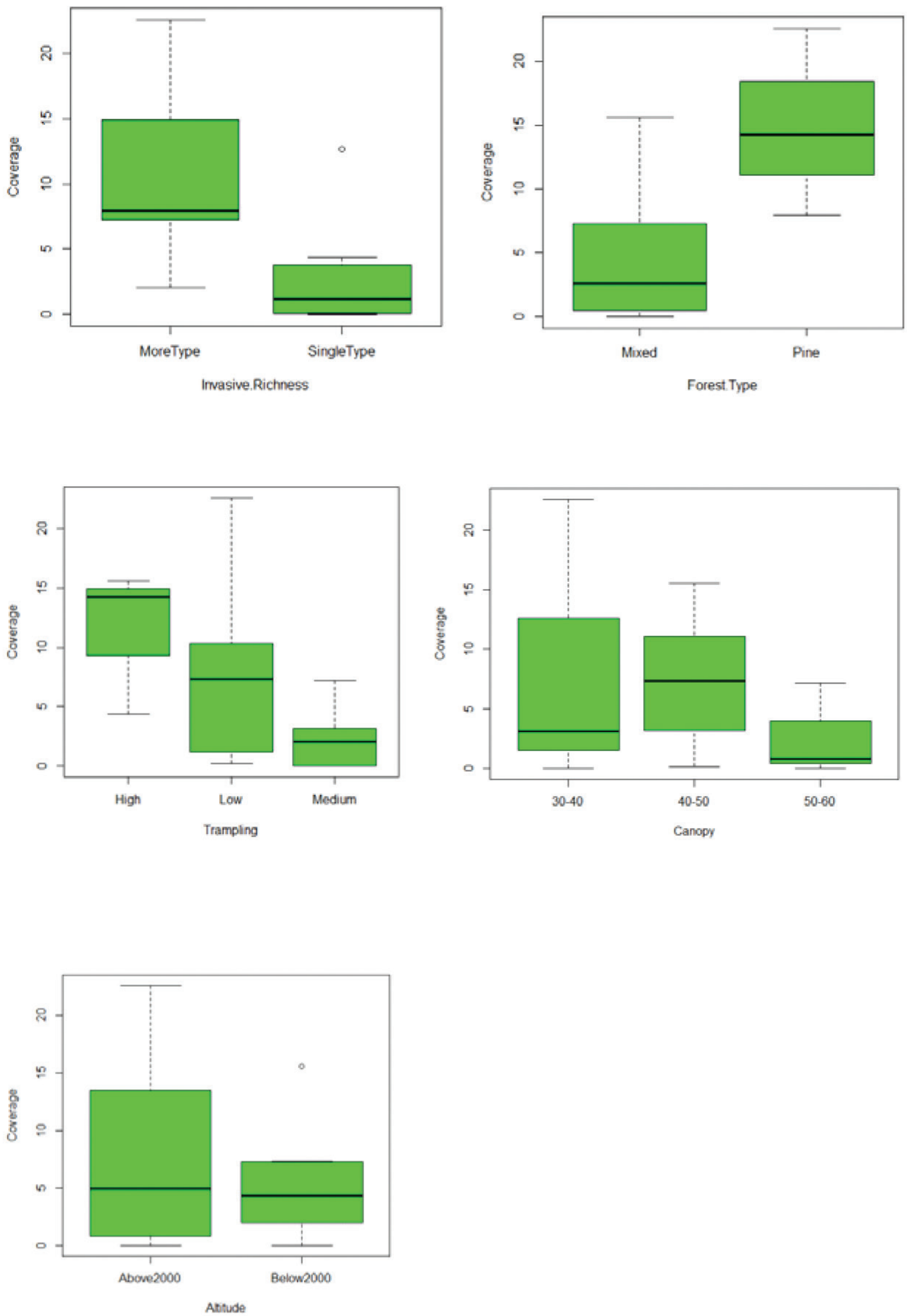


Figure 3: Invasive species coverage with different covariant.

Seedling, Sapling, and Invasive species Cover

The number of seedlings, sapling and their diversity were different with the extent of invasive species coverage (Figure 4). The number of seedling presence was significantly ($W = 42$, $p = 0.009$) different from invasive species coverage. The seedling number was more in 0-10% invasive species coverage plot in comparison to above 10% coverage plots. Likewise, the presence of saplings was also significantly ($W = 39$, $p = 0.029$) different from invasive species cover. Sapling was more in 0-10% coverage. The diversity of seedling and sapling also significantly different ($W = 36$, p-value = 0.055) and $W = 38$, $p = 0.032$ respectively with the invasive species coverage percentage.

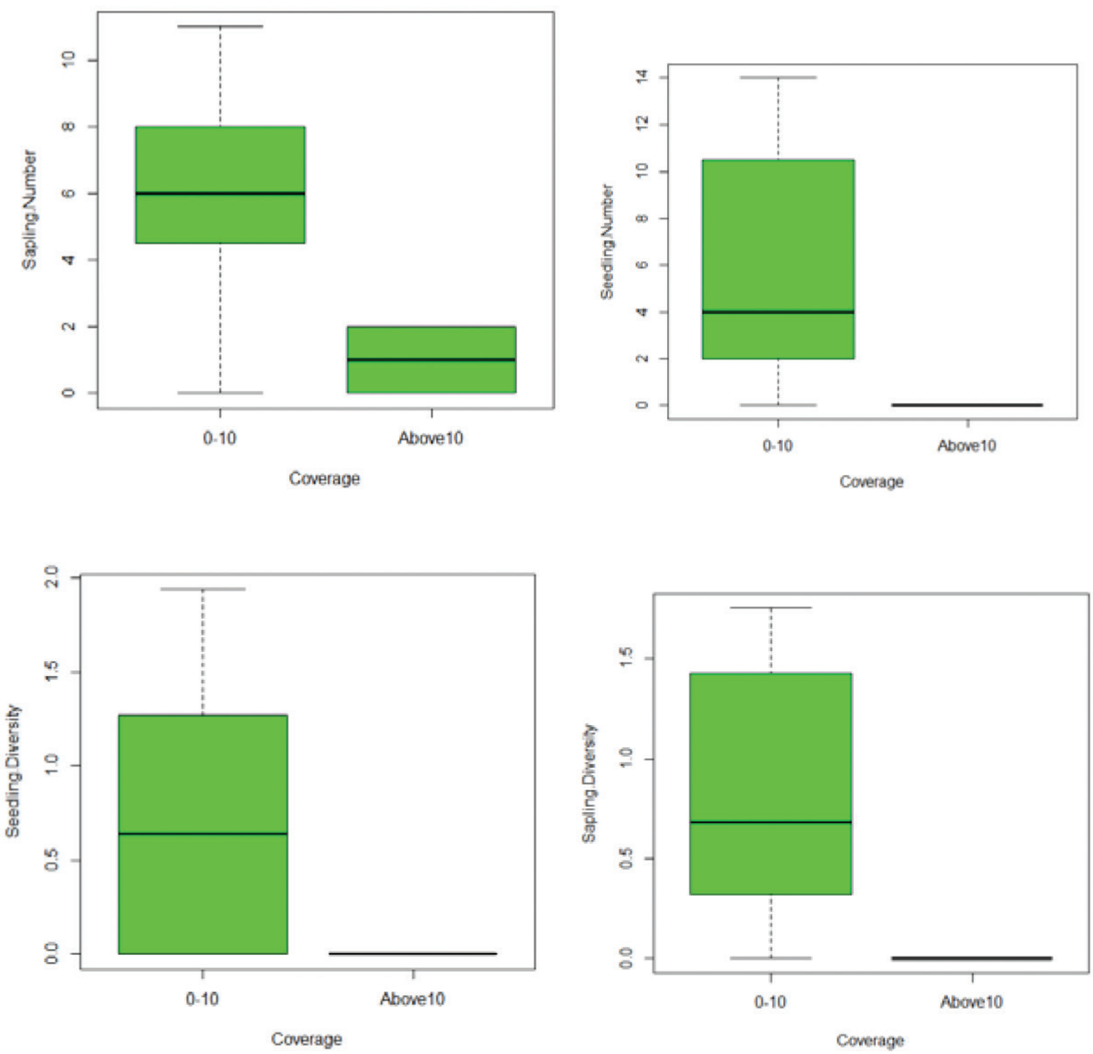


Figure 4: Seedling and sapling number and diversity with invasive species coverage

Invasive species Cover and Covariant

In the case of the pine forest, the invasive species coverage was higher similar to other studies (Dyderski & Jagodzinski, 2020). Additionally, *Eupatorium adenophora*was found to have the highest coverage in the study plots. It has been observed that invasive species, particularly, *Eupatorium adenophora,*are able to employ their adaptive mechanisms to form dominant coverage in the Pine forest (Callaway & Ridenour, 2005). Similarly, invasive species are even able to escape the negative reaction sent out by the native pine species and increase their coverage in the forest (Dyola, et al., 2020). On the contrary, high species diversity in mixed forest regions contributes to the moderation of prevalent invasive species resulting in decreased invasion coverage (Haas et al., 2011).

The invasive species coverage in the study plots was found to be significantly higher where more than 2 types of invasive species were prevalent. Hejda et al. (2009) also found similar results when analyzing native species richness in the invaded communities. The higher the invasive species richness, the higher becomes the invasion coverage because the prevalence of more invasive species within an area accounts for reduced regeneration rate of the native plants (Chaudhary et al., 2020). The plots the study area nearer to villages within the trekking trail had higher invasive species richness with the prevalence of species such as *Eupatorium adenophora, Bidens pilosa, Galinsoga parviflora,* and *Ageratum conyzoides*. With more human movement and involved disturbances such as trampling, there also occurs dispersion of invasive species seeds resulting in an increase in their coverage area (Hobbs & Huenneke, 1992).

High invasive species coverage was recorded in the area that had high and low trampling. Similar case was encountered by Winkle (2014) in their study regarding spread of invasive species in urban natural areas. Disturbance such as trampling or soil movement could act primarily as a source of invasion as they provided a rougher surface on which seeds are embedded, as a result of which disturbance provided safer space for seeds of invasive species to grow (Hobbs & Atkins, 1988). It can be predicted that intermediate disturbance was needed for management of invasion which was supported by the Intermediate Disturbance Hypothesis by Wilkinson (1999), which thus, suggested that at intermediate levels of disturbance, diversity was maximized because species that thrived at both early and late successional stages coexisted, as a result, species diversity can be maintained while managing as well as controlling invasion.

The coverage of the invasive species was found to be decreasing with increasing canopy cover. This result was in line with the research done by Khania and Shrestha (2020) and Sharma et al. (2019). This is because invasive species are understory shrubs in the forest ecosystem and are unable to compete with trees for lights, thus, their coverage decreases in areas with higher canopy cover (Sharma, et al., 2019). Additionally, most of the invasive species-area abundant in areas that are open with plenty of light availability, which is hindered in forest areas with higher canopy cover (Mavimbela et al., 2018).

The invasive species coverage was found slightly higher in the study plots above 2000m (until 2140m), however, the increment was not that significant. The plots taken during the study, that is, 1400m to 2140 is within the distribution range of the invasive species prevalent in the study area, thus altitudinal difference was not found to be statistically significant (Shrestha, 2016).

Seedling and Sapling Presence and Invasive Species Coverage

The seedling and sapling numbers were significantly low with the coverage of invasive species above 10% in comparison to 0-10% coverage which might have suppressed due to invasive species activities through disruptive belowground mutualisms and secretion of inhibitory chemicals (Stinson, et al., 2006). Similar case was encountered by Chaudhary et al. (2020) and Dyderski and Jagodzinski (2020). The invasive species produce allelochemicals which create an unfavorable environment for the growth and development of native plant seedlings and saplings (Seastedt et al., 2008). Likewise, as seedlings and saplings are particularly vulnerable to competition with the understory of the forest ecosystem, over light availability and nutrition, higher invasive species coverage slows down seedling and sapling presence (Dyderski & Jagodzinski, 2019).

The seedling and sapling diversity were found to be higher in the plots with less than 10% invasive species coverage similar to Ekanayake et al., (2020) which might be due to interaction with the invasive species including the coverage of the invasive species. Similar result was obtained by Chaudhary (2015). Likewise, as invasive species coverage increases with its richness, with the increase in the coverage of the invasive species, there also occurs an increase in the invasive species richness (Chaudhary, 2015). As a result, it can affect the species diversity and richness of other native vegetation due to the secretion of high amounts of allelopathic and phytotoxic chemicals. Likewise, in native forests, invasive plant species were able to dictate the stratification, which suppressed the growth of saplings and eventually species diversity (Keely, 2006). Therefore, we recommend suppressing the presence of invasive species in the study area which might be done by the involvement of the local community and park authorities.

Conclusion

This study has found invasive species and impact of invasive species on trees in Shivapuri Nagarjun National Park, Central Nepal. A total of nine invasive specieswere investigated and recorded. *Eupatorium adenophora* was the most dominant invasive species recorded in this park.The invasive species coverage was significantly depending on types of forestand invasive species richness.The number of seedlings, sapling and their diversity were significantly different with the extent of invasive species coverage.The park and local people should work together and form effective plan and implement it to lower the number of invasive species and their impact on trees.

Acknowledgements

We would like to thank the Department of National Parks and Wildlife Conservation, Nepal for providing permission to conduct this work, the staff of Shivapuri Nagarjun National Park and local people for providing support in the field.

References

- Brunel S, Fernández-Galiano E, Genovesi P et al (2013) Invasive alien species: a growing but neglected threat? In: Late lessons from early warning: science, precaution, innovation. Lessons for preventing harm. EEA report 1/2013, Copenhagen, pp 518–540

- Callaway, R. M., & Ridenour, W. M. (2005). Novel weapons: Invasive success and the evolution of increased competitive ability. *Biological Sciences Faculty Publications*, 223.

- Chaudhari, S. K., Rajbanshi, P., Karki, R., & Dahal, D. (2021) Distribution of Invasive Plant Species along Elevation Gradient in Eastern Nepal. *Integrating Biological Resources for Prosperity*.

- Chaudhary, R., Shrestha, B. B., Thapa, H., & Siwakoti, M. (2020). Status and impacts of invasive alien plant species in Parsa National Park, central Nepal. *Banko Janakari*, 30(1), 21-31. https://doi.org/10.3126/banko.v30i1.29179

- Davis, M.A., Grime, J.P. and Thompson, K. 2000. Fluctuating resources in plant communities: a general theory of invisibility. Journal of Ecology 88: 528-534.

- Dyderski, M. K., & Jagodzinski, A. M. (2019). Similar impacts of alien and native tree species on understory light availability in a temperate forest. *Forests*, 10 (11), 951. https://doi.org/10.3390/f10110951

- Dyola, N., Bhuju, D. R., Kharal, D. K., Aryal, S., Gaire, N. P., & Hitler, L. (2020). Growth pattern of Pinus roxburghii under different regimes of invasive species in Panchase, Nepal Himalayas. *Pakistan Journal of Botany*, 52(1). http://dx.doi.org/10.30848/PJB2020-1(33)

- Ekanayake, E., Cirella, G. T., & Xie, Y. (2020). Impacts of community forestry on forest condition: Evidence from Sri Lanka's intermediate zone. *Journal of Sustainable Forestry*, 15(9), e0239405. https://doi.org/10.1371/journal.pone.0239405

- Haas, S. E., Hooten, M. B., Rizzo, D. M., & Meentemeyer, R. K. (2011). Forest species diversity reduces disease risk in a generalist plant pathogen invasion. *Ecology Letters*, 14(11), 1108-1116. https://doi.org/10.1111/j.1461-0248.2011.01679.x

- Hejda, M., Pysek, P., & Jarosik, V. (2009). Impact of invasive plants on the species richness, diversity and composition of invaded communities. *Journal of Ecology*, 97(3). https://doi.org/10.1111/j.1365-2745.2009.01480.

- Hobbs, R. J., & Atkins, L. (1988). Effect of disturbance and nutrient addition on native and introduced annuals in plant communities in the western Australian wheatbelt. *Australian Journal of Ecology*, 13(2), 171-179. https://doi.org/10.1111/j.1442-9993.1988.tb00966.x

- Hobbs, R. J., & Huenneke, L. F. (1992). Disturbance, diversity and invasion: Implications for conservation. *Conservation Biology*, 6(3), 324-337.

- Keely, J. (2006). Fire Management Impacts on Invasive Plants in the Western United States. *Conservation Biology*, 20(2), 375-384. https://doi.org/10.1111/j.1523-1739.2006.00339.x

- Khania, L., & Shrestha, B. B. (2020). Forest regrowth reduces richness and abundance of invasive alien plant species in community managed Shorea robusta forests of central Nepal. *Journal of Ecology and Environment*, 44(1), 12. https://doi.org/10.1186/s41610-020-00158-7

- Mavimbela, L. Z., Sieben, E. J., & Proches, S. (2018). Invasive alien plant species, fragmentation and scale effects on urban forest community composition in Durban, South Africa. *New Zealand Journal of Forestry Science*, 48(1), 19. https://doi.org/10.1186/s40490-018-0124-8

- Seastedt, T. R., Callaway, R. M., Pollock, J. L., & Kaur, J. (2008). Allelopathy and plant invasions: Traditional, congeneric and bio-geographical approaches. *Biological Invasions*, 10, 875-890. https://doi.org/10.1007/s10530-008-9239-9

- Sharma, L. N., Adhikari, B., Watson, M. F., Karna, B., Paudel, E., Shrestha, B. B., & Rijal, D. P. (2019). Forest canopy resists plant invasions: a case study of Chromolaena odorata in sub-tropical Sal (Shorea robusta) forests of Nepal. *bioRxiv*, 747287. https://doi.org/10.1101/747287

- Shrestha, B. B. (2016). *Invasive alien plant species in Nepal.* Frontiers of Botany.

- Simberloff D, Martin JL, Genovesi P et al (2013). Impacts of biological invasions: What's what and the way forward?*Trends Ecology Evolution* 28, 58–66

- Simberloff, D. (2009). The role of propagule pressure in biological invasion. Annual Review of Ecology, *Evolution and Systematics* 40, 81-102.

- Spear D, Foxcroft LC, Bezuidenhout H et al (2013). Human population density explains alien species richness in protected areas. Biol Conserv 159:137–147

- Stinson, K. A., Campbell, S. A., Powell, J. R., Wolfe, B. E., Callaway, R. M., Thelen, G. C., . . . Klironomos, J. N. (2006). Invasive plant species suppresses the growth of native tree seedlings by disrupting belowground mutualisms. *Plos Biology*, 4(5), e140. https://doi.org/10.1371/journal.pbio.0040140
- Tiwari, S., Siwakoti M., Adhikari, B., & Subedi, K. (2005). An Inventory and Assessment of Invasive Alien Plant Species of Nepal. IUCN- The World Conservation Union, Nepal
- Wilkinson, D. M. (1999). The disturbing history of intermediate disturbance. In *Oikos* (pp. 145-147).
- Winkle, J. E. (2014). *Informal trails and the spread of invasive species in urban natural areas: 'Spatial analysis of informal trails and their effects on understory plant communities in Forest Park, Portland, Oregon.* Portland State University.

Assessment of Bacterial Contamination in Drinking water of Schools of Tokha Municipality, Kathmandu

Ganga Shrestha[1,2]*, Mohan Bikram Shrestha[2], Rejina Maskey Byanju[1]
[1,3] Central Department of Environmental Science, Kathmandu, Nepal
[2] Wildlife Research and Education Network (WREN), Kathmandu, Nepal
*Corresponding email: shresthaganga080@gmail.com

Abstract

Assessment of drinking water quality is being crucial especially in school institutions since children spend most of the time in school premises. The aim of this study was to assess bacterial contamination of the selected schools of Tokha Municipality. Total of 17 water samples from Ward 1, 2 and 3 were sampled and membrane filtration (MF) technique was used to analyses total coliform and fecal coliform incubated for 37 ^{0}C and 44 ^{0}C respectively. Multiple drinking water sources were found in the study area such as natural springs, piped-line system, bottled water and private wells. Almost all of the water samples exceeded WHO guideline and National Drinking Water Standards which implied none of the water samples are safe for drinking. Very few schools were found to adopt purification measures while other used to supply directly. Water samples of school were even not tested once in many schools for microbial analysis. Therefore, school management need to be responsible in coming days to ensure safe drinking water not just for children, for the wellbeing of the society and Nation.

Keywords: *Children, total coliforms, fecal coliforms, Purification method*

Introduction

Sustainable water resource management is one of the greatest issues for developing countries like Nepal due to population growth, changing lifestyles and unmanaged urbanization (Wheater, 2015). Many south Asian cities like Kathmandu are facing water scarcity for many years and had provided with inadequate and unreliable water supply services (Chapagain, 2012). Due to which, many households depends upon multiple water sources such as groundwater like stone spouts, public/private wells as cheap and easy source whereas tanker and jar water as an expensive source (Shrestha et al., 2016). The unreliable and inadequate water supply not just increase the risk of health and safety, but also compromise quality of life for long run (Meier, 1977).

School is prominent places, after the family in child's dailylife. The maximal time duration of children is spent in school. Safe drinking water, good sanitation and hygiene in school bears remarkable role in children health and education. Good health of children reduces school absence thereby enhancing competence and delivering better academic performance. In fact, the good health of children ultimately results in social and economic development of country (UNICEF, 2006). However, securing safe drinking water, sanitation and hygiene have been major challenge to school administrators. Schools are high-risk environments due to both the complex nature of their drinking water systems and the vulnerability of the users (Edition, 2011). Each year, 1.1 million children die due to diarrheal diseases (Steiner et al., 2007) and lose 272 million school days due to diarrhea (UNICEF, 2010). Absence in school is indicator of health status among children (Houghton 2003). Hence, provision of safe drinking water, sanitation and hygiene in school is utmost for minimizing school absence.

Therefore, with the objectives to examine total coliform and fecal coliform in drinking water and to understand measures applied by school management for safe drinking water provision in schools, this study was conducted in Tokha Municipality.

Materials and Methods

Study Area

This study aims at assessing the bacteriological quality analysis of water in selected schools of Tokha Municipality. Tokha Municipality lies in northern valley of Kathmandu districts. It has beautiful and pristine ambience with the presence of Shivapuri National Park at the back. The studied schools of this municipality (Annex 2) were based urbanization. This includes Rural (ward-1) and sub-urban (Ward-2 and 3). The access to drinking water facility was categorized accordingly with the urbanization status. Access of drinking water in ward-1 is natural stream from nearby Shivapuri forest. While majority of drinking water in ward 2 and 3 are supplied by water distributor locating in ward-2 whereas rest have water supplement from private water suppliers (bottled water) and underground water extraction (Dug well and deep boring). The study was conducted between November-December, 2020.The total of 18 schools and its location is shown in below study area map (Figure 1).

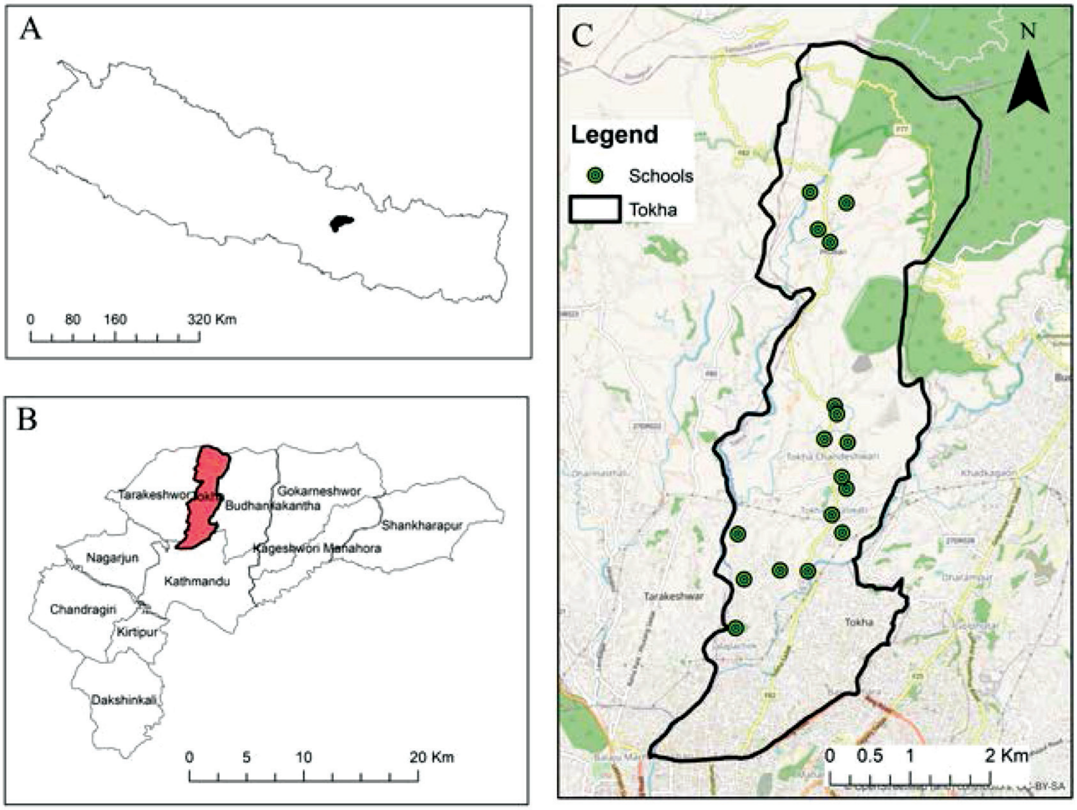


Figure 1: Map of Study area A) Map of Nepal B) Map of Kathmandu district C) Map of Study area with sampling sites

Water Sample Analysis

Water samples were collected from point of use in every schools except Divine due to winter vacation. The sample bottle was rinsed with sample itself for 3 times. Analysis was processed within 6 hours of collection. The analysis of coliform bacteria was carried out in the lab of Central Department of Environmental Science (CDES). For it, membrane filtration (MF) technique was used. In this method, the absorbent pad was placed in sterile Petri dish with sterile forceps. Then, it was soaked with 20 ml nutrient media i.e. M-endo broth. 100 ml of water sample was poured into funnel of sterile filter apparatus through filter paper size 0.45µm. After applying a vacuum to suction flask, carefully the membrane filter was removed by holding its edge and placed it above the pad or agar. The Petri dish was marked and incubated at 44 ^{0}C for fecal coliform and at 37 ^{0}C for total coliform separately for 24 hours. After incubation, the colonies were counted (Bartram & Pedley, 1996).

$$\textit{No. of colonies per 100 ml} = [\textit{No. of colonies} \div \textit{Volume filtered}] * 100$$

School Surveys

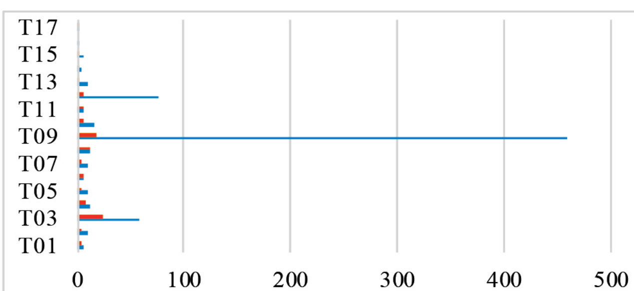
Using a structured interview and close ended type questionnaire was developed to get background knowledge of schools and its water supply. The questionnaire survey divided into sub divisions as school details, drinking water source, school absence and water borne disease. It includes sources of drinking water, water storage mechanism, previous water quality testing, drinking tap location, reason of school absence and its number and age groups etc. The survey questions are provided in Annex 3.

Results and Discussion

Water Sample Analysis

Total coliform and fecal coliform were analyzed in which range of total coliform was from 1 to 460 whereas fecal coliform ranged from 0 to 24. The values of total coliform and fecal coliform are shown in below figure 2.

Almost all water samples exceed the WHO limit (WHO, 1993) and Nepal Standards for Drinking water (National Drinking Water Quality Standards, 2005) for total coliform and fecal coliform. The U.S. EPA (Environmental Protection Agency) determined the presence of total coliforms is possible health concern. Generally total coliforms in environment are not harmful but if present in water persist for long, is a problem with water treatment or the pipes that distribute water. Whereas, fecal coliforms signify the presence of sewage contamination of a waterway and possible presence of other pathogenic organisms. Hence, bacteriologically larger proportion of water samples were found to be unacceptable.



	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10	T11	T12	T13	T14	T15	T16	T17
FC	4	3	24	7	4	6	3	11	17	6	5	5	1	2	2	0	1
TC	6	9	58	11	10	6	9	12	460	16	5	76	10	3	5	1	2

Figure 2: Total coliform and fecal coliform in water sample

Schools Survey

Out of 17 schools, 6 schools have technology that treat drinking water whereas 11 of other schools are deprived of any treatment and supply directly to school children. Routine water quality testing is very much necessary as it ensures the health and safety of school students and staff. Only few percentage of schools (11.76%) tend to test drinking water time and again whereas 23.53% of schools had tested once to check the efficiency of filtration system after its installation. Otherwise majority (64.71%) have never done this before. This could be presented in below figure 3.

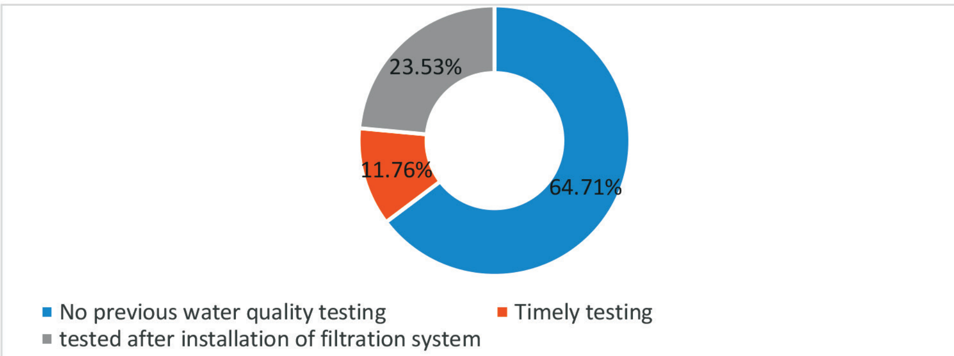


Figure 3: Status of Water quality testing

There was various reason of school absence. Among which, waterborne disease was common among the students in this study. With access of good piped water supply and proper sewage connection to houses, 1863 million days of school attendance would be gained due to less diarrheal illness (WHO, 2004).

Nitin memorial school, Satya Sai school and Angel paradise school have infirmary ward within school premises whereas others don't have. Annually, few students of age group 2 to 12 years were found vulnerable towards water borne disease like diarrhea and dysentery.

Among total samples, four samples were collected from Ward No. 1 consist of four schools (T09, T10, T11 and T12) which have same natural source of water i.e. from springs generated through Shivapuri Jungle. They do not adopt any purification method and consume directly. This may be one of the reason in observing total coliforms and fecal coliforms in water samples. According to Frisell et al. (2011), purification methods are successful in removing total coliform and fecal coliform when done properly. Comparing these four schools, T11 is found to have less total coliform (5) as well as fecal coliform (5) than T10(16,6), T12(76,5) and T9(460,17) respectively. T11 lies at the top hill with less human disturbances whereas human settlement increased as we move downward (T10, T12 and T9). Fecal bacteria and other bacteria's densities were highly related to the density of housing, population, development, percent impervious area and apparent domestic animal density (Young & Thackston, 1999).

T01, T02, T15 and T17 have jar water as a source of drinking water to school children. They directly consume bottle water without any treatment thinking that is safe to drink. It was found total coliform and fecal coliform varying its number according to the jar company. Most population rated their drinking jar water good but found to be highly questioning as one research done by Subedi & Aryal (2010) found 91.2% contaminated with total coliforms and 59.6% contaminated with fecal coliforms. This result is also supported by another one in which it was found that about 66% were heavily contaminated with coliforms in Jan/Feb month and 89% in Feb/March (Tamrakar et al., 2017). Ghimire et al. (2013) and Bhandari et al. (2009) also supported this result. From this, it can have concluded that jar water samples are unsatisfactory for drinking purpose without doing some treatment purpose.

T03, T05, T06 and T07 have water supplement system. T03 have highest total coliform and fecal coliform than T05, T06 and T07. The reason may be due to absence of any treatment for purification of drinking water. Koju et al. (2014) found 80% of 46 piped water samples were contaminated with total coliform at consumer tap. T04 uses well water for drinking purpose and they treat water through chlorination process. According to respondent, they use piyush (chlorination agent) 3 drops in 20ml water. But the recommendation dose is 3 drops to disinfect 1 liters of water. This incorrect dose of disinfectant may be the reason of observing total coliform and fecal coliform in drinking water.

T05, T06, T07, T08, T13, T14 and T16 have automatic water purification system which consist of pre-treatment, reverse osmosis and disinfection and a hybrid dispensation system. Despite, it showed total coliform and fecal coliform. The reason may be due to use of different companies in removing total coliform and fecal coliform. Its installation time, storage tank and nozzle contamination plays important role in coliforms number. Nowadays, water vending machine (WVM) industry has experienced an increase over the past few years but its efficiency is still unknown.

Conclusion

Water samples collected from 17 schools were not free from coliform. Almost all water samples exceed WHO guideline value for drinking water and National drinking water standards. The total coliform range from 1 to 460 and fecal coliform range from 0 to 24. High number of coliforms were seen in those samples where direct water consumes from the spring source, without any pretreatment. Very few schools feel ownership regarding supply of safe drinking water to the students of Tokha since timely testing of water was not seen. This increase the threat to health from water-borne diseases leading to absenteeism and hinders children's health and education. Hence purification methods should adopt along with timely water quality testing. Along with purification, storage tanks and other vessels should be clean time and again to remove bacteria.

Acknowledgements

At first, I would like to express great gratitude to Central Department of Environmental Science, Kirtipur for providing this opportunity to conduct this study. I am grateful to all those schools who have provided me positive response during my field visit.

Finally, I would like to express my sincere thanks to my family members for their continuous help and encouragement.

References

- Bartram, J., & Pedley, S. (1996). Water Quality Monitoring- A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes. United Nations Environment Programme; World Health Organization. https://doi.org/10.1002/ejoc.201200111.

- Bhandari, P., Khanal, S., Shakya, R., & Joshi, D.R. (2009). Microbial quality of jar water sold in Kathmandu valley. *J. Food. Sci. Technol.,* 5, 150-152.

- Chapagain, D.P. (2012). Urban water supply sector reform in Kathmandu Valley. *J. Inst. Eng*, 9, 130-141.

- Edition, F. (2011). Water quality for drinking: who guidelines. *Springer Reference*. https://doi.org/10.1007/springerreference_30502.

- Frisell, M. K., Hyatt, R. S., & Matson, D. M. (2011). *In-home methods for water purification in rural Ecuador.*

- Ghimire, G., Adhikari, B., & Pradhan, M. (2013). Bacteriological analysis of water of Kathmandu valley. *Med. J. Shree Birendra Hosp*, 12, 19-22.

- Houghton, F. (2003). The use of primary / national school absenteeism as a proxy retropective child health status measure in an environmental pollution investination. *Journal of the Royal Institute of Public Health*, 117, 417-423.

- Koju, N.K., Prasai, T., Shrrestha, S.M., & Raut, P. (2014). Drinking water quality of Kathmandu Valley. Nepal J. Sci. Technol, 15, 115-120.

- Meier, W.L.J. (1977). Climate, climate change and water supply; The national academies press: Washington, DC, USA.

- National Drinking Water Quality Standards (2005). Ministry of Physical Planning and Works Singhadarbar kathmandu National Drinking Water Quality Standards , 2005 Implementation Directives for National Drinking Water Quality Standards , 2005 Government of Nepal Notice issued by Ministry of Physical Planning.

- Shrestha, S., Yoko, A., Kondo, N., Rajbhandari, S., Bhattarai, A.P., Bista, N., Kazama, F., Nishida, K., Timilsina, H.P., & Shindo, J. (2016). Househole water use in the Kathmandu Valley: A dry season survey, ICRE WASH-MIA report, ICRE; University of Yamanashi: Kofu, Japan.

- Steiner, T. S., Samie, A., & Guerrant, R. L. (2007). Infectious diarrhea: New pathogens and new challenges in developed and developing areas. *Chinese Journal of Infection and Chemotherapy*, 7(2), 147. https://doi.org/10.1086/505874.

- Subedi, M., & Aryal, M. (2010). Public perception about drinking jar water and its bacteriological analysis. *Nepal Medical College Journal : NMCJ*, 12(2), 110–114.

- Tamrakar, P., Shakya, S. K., & Baniya, C. B. (2017). Physico-Chemical and Bacteriological Composition in a Metropolitan Drinking Water Distribution System in Kathmandu. *Journal of Institute of Science and Technology,* 22(1), 159–164. https://doi.org/10.3126/jist.v22i1.17768.

- UNICEF (2010). Raising Clean Hands: Advancing learning, health and participation through WASH in schools - Joint Call to Action 2010. Change, 20. Retrieved from http://www.unicef.org/media/files/raisingcleanhands_2010.pdf

- UNICEF (2006). School Sanitation and Hygiene Education Program Guideline . Retrieved from https://media.ifrc.org/wp-content/uploads/sites/13/2018/10/nepal-rcs_final-school-sanitation-hygiene-programme-guidel.pdf

- Wheater, H.S. (2015). Water Security: Science and management challenges. *Proc. Int. Assoc. Hydrol. Sci*, 366, 23-30.

- WHO (1993). *Guidelines for Drinking Water Quality*, Volume I, II and III, World Health Organization, Geneva.

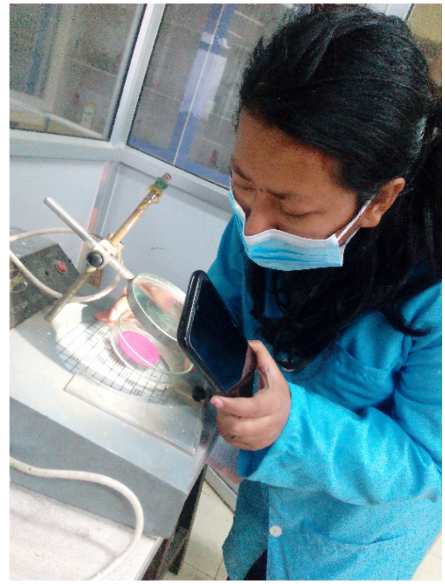
- WHO (2004). Water, sanitation and hygiene links to health. Geneva.

- Young, K.D., & Thackston, E.L. (1999). Housing Density an Bacterial Loading in Urban Stream. *Journal of Engineering, 125(12), 1177-1180*

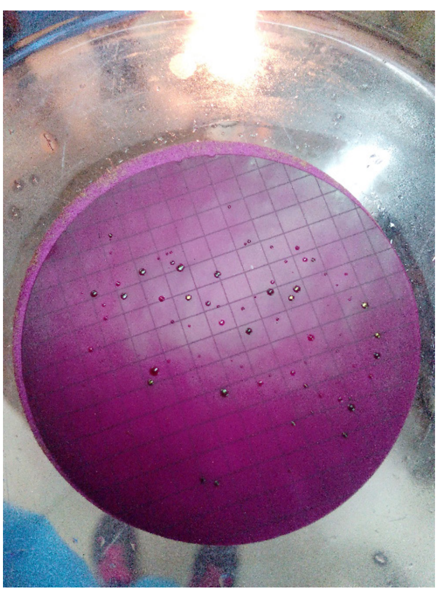
Appendices

Annex 1

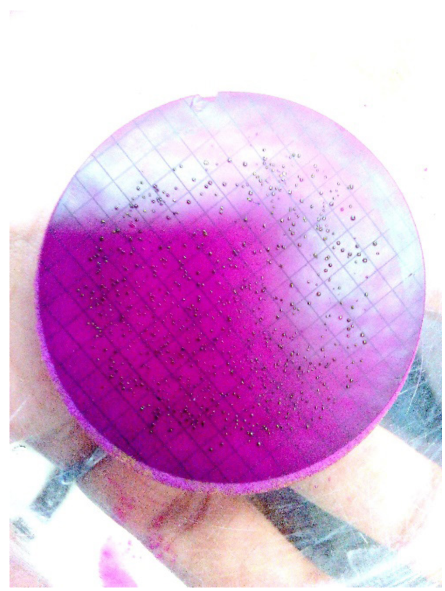
Photograph 1: Researcher conducting practical in lab



Photograph 2: Researcher counting total coliforms in colony counter



Photograph 3: Number of total coliforms present



Photograph 4: Too many to count (TMTC) number of coliforms

Annex 2

List of Schools of Tokha Municipality

<table>
<tr><th rowspan="2">S.N</th><th rowspan="2">Samples</th><th colspan="3">Sampling location</th><th rowspan="2">Ownership</th></tr>
<tr><th>Name</th><th>School type</th><th>Ward</th></tr>
<tr><td>1</td><td>T01</td><td>Oasis School</td><td>Secondary school</td><td rowspan="4">2</td><td rowspan="2">Private</td></tr>
<tr><td>2</td><td>T02</td><td>Ganesh School</td><td>Secondary school</td></tr>
<tr><td>3</td><td>T03</td><td>Chandeshori School</td><td>Lower secondary</td><td>GON</td></tr>
<tr><td>4</td><td>T04</td><td>Laxmipur School</td><td>Secondary</td><td>Private</td></tr>
<tr><td>5</td><td>T05</td><td>Saraswati School</td><td>Higher Secondary</td><td rowspan="4">3</td><td>GON</td></tr>
<tr><td>6</td><td>T06</td><td>Bindavasini School</td><td>Secondary</td><td rowspan="4">Private</td></tr>
<tr><td>7</td><td>T07</td><td>Amar School</td><td>Secondary</td></tr>
<tr><td>8</td><td>T08</td><td>Nitin Memorial School</td><td>Higher secondary</td></tr>
<tr><td>9</td><td>T09</td><td>Public School</td><td>Secondary</td><td rowspan="4">1</td></tr>
<tr><td>10</td><td>T10</td><td>Shree Boudeshor School</td><td>Higher secondary</td><td>GON</td></tr>
<tr><td>11</td><td>T11</td><td>JhorMahangkal School</td><td>Secondary</td><td>GON</td></tr>
<tr><td>12</td><td>T12</td><td>Triveni Sadan School</td><td>Secondary</td><td rowspan="6">Private</td></tr>
<tr><td>13</td><td>T13</td><td>Satya Sai School</td><td>Secondary</td><td rowspan="5">3</td></tr>
<tr><td>14</td><td>T14</td><td>New Malashree School</td><td>Lower secondary</td></tr>
<tr><td>15</td><td>T15</td><td>Angel’s Paradise School</td><td>Lower secondary</td></tr>
<tr><td>16</td><td>T16</td><td>Edu Summit School</td><td>Lower secondary</td></tr>
<tr><td>17</td><td>T17</td><td>Cupid Children School</td><td>Kinder garden</td></tr>
</table>

Annex 3

School Drinking Water Quality Study

Date:

School Details				
School Name:				Type: Government/ Private
Address:				Contact:
Contact Person:				Designation:
GPS:		Establishment Date:		(In years)
No. of Students: Total	Boys:	Girls:		No. of Teachers:

Drink water Source	
Drinking water Source: Springs/Well /Sprout/ Aquifer/ water supplement system/Tanker/Jar water	
Water storage: Direct supplement through tap/Storage tank	
Previous Water quality Testing: Yes/ No	If yes, when…
Drinking water Tap Location (Observe and mention the tap location ambience)	

School Absence and Water Borne Disease						
Reason of School Absence (mention number of school absence (approx.) in designated reason below)						
Casual	Travel	Accident	Disease	Mensuration	Assignment	
If any other reasons..						
Number of school absence due to water borne diseases in a year (List water borne disease and any relevant information below) 1. 2. 3. 4.						
Age of school absence (Mention percentage in space below)						
2-4	5-6	7-8	9-10	11-12	13-14	15-16
Infirmary ward: Present/Absence						

Transhumance Herders' Perceptions Towards the Change in Temperature and Precipitation in Red Panda (*Ailurus fulgens* Cuvier 1825) Habitats in Jajarkot, Karnali Province, Nepal

Badri Baral[1,2]*, Sunita Shrestha[3,4], Dipak Raj Basnet[2], Ganesh Bahadur Magar[2], Parashuram Bhandari[2], Jeevan Rai[2,3], Sudeep Bhandari[1,2]
[1] Nepal Environmental Research Institute, Tarakeshwor-9, Kathmandu, Nepal.
[2] Nature Conservation Initiative Nepal, Kathmandu, Nepal
[3]Central Department of Environmental Science, Kirtipur, Kathmandu, Nepal
[4]Nepal Academy of Science and Technology, Lalitpur, Nepal
*Corresponding email: badribaral2071@gmail.com

Abstract

The endangered red panda (Ailurus fulgens)is endemic to the Himalayas, including Jajarkot. Forest-dependent agro-pastoralists in Jajarkot rely on natural resources for their livelihoods in prime red panda habitats. This paper describes how agro-pastoralists perceive prevailing climate change threats and how they together with endangered red panda are sustaining in spite of these threats based on personal interviews, focus group discussions, key informant interviews, and observation methods. The results of the study revealed that the perceptions of the agro-pastoralists correspond with the increasing trend of temperature and the changing (both increasing and decreasing) trends of precipitation. Moreover, the agro-pastoralists have perceived the decrease in snowfall and reported the appearance of new forage and pasture species in the red panda habitat. The findings will be useful to understand the impact of climate change in the red panda range and devising adaptation strategies in these areas.

Keywords: *Biophysical indicators, climate change, interview,pasture, pastoralists*

Introduction

About 129.91 million (1.705% of the global total population) resideabove 2,500 masl up to 5000 masl (Tremblay & Ainslie, 2021)with a higher incidence of poverty than in the lowlands in the same regions (Hunzai et al., 2011).Transhumance pastoralism in high-altitude mountains is a unique age-old practice and adaptive strategy of the seasonal migration of livestock and humans between many agro-ecological zones and make their living through income from cattle-based products complemented by collection and trade of non-timber forest products (NTFPs) (Agrawal, 2010; Rota &Sperandini, 2010).Transhumant pastoralism supports the subsistence livelihoods and simultaneously increases pressure on forests and alpine meadows in Nepal (Khadka & James, 2016). Mountain pasture land ecosystems in Nepal extend about 12 percent of the country's land area comprising about

79 percent of these ecosystems in the High Mountains and High Himal areas and 17 percent in the Middle Mountains (GoN, 2014). Due to poor management, only 37 percent of the forage is accessible to livestock in Nepal (Ning et al., 2013).

Endemic to the Himalayas, the red panda (*Ailurus fulgens*) is listed as 'Endangered' by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species(Glatston et al., 2015), and the National Red List of Nepal (Jnawali et al., 2011).Due to variations in climate and topography across the entire range, the red panda shares different habitat rangesand vegetation compositions, including evergreen forests, evergreen, and deciduous mixed broadleaf forests, deciduous forests, deciduous and coniferous mixed forests, and coniferous forests with associated bamboo thicket understories (Yonzon et al., 1991a; Wei et al.,1999).In a pastoral system, livestock shelters are temporary and move across pastures and forests (Fox et al., 1996), which are considered potential habitats for the red panda (Bista et al., 2017). Livestock grazing is considered a major threat to the red panda in protected areas in Nepal, including in Langtang National Park, Dhorpatan Hunting Reserve, outside the protected area in Jajarkot (Yonzon &Hunter, 1991; Sharma &Belant, 2009, Baral, 2014), and elsewhere in Bhutan (Dorji et al., 2012).

Climate plays an important role in determining species distributions and evaluating the influence of climatic variables across a large geographic area (Morelle & Lejeune, 2015) to provide information about suitable habitats for a given species.Climatic variables are the dominant driving factors as opposed to distal variables such as elevation and topography, which are used frequently but have a low predictive performance (Bradie & Leung, 2017). Yonzon et al., (1997) built a potential habitat model incorporating annual precipitation; while Kandel et al., (2015)predicted the same based on temperature-associated in the vast Hindu Kush Himalaya region (Kandel et al., 2015). Climate change can cause substantial species range contractions and extinctions and lead to a disproportionate distribution of species along ecological zones (Wilson et al., 2007). Meteorological data showed warmer and drierclimates in the red panda habitat in recent decades and forecast this pattern to continue in the future(Wang et al., 2010).The mountains are highly sensitive and prone to climate change (Viviroli et al., 2011, IPCC, 2019) and its impacts are more pronounced in red panda habitats than in low-altitude regions. People adopting natural resources-based livelihood options are affected more and their perceptions might be different. These perceptions coupled with the modern climate model might be accurate and can be better applied tothe assessments of climate change (Alexander et al., 2011; Petheram et al., 2010; Sánchez-Cortés & Chavero, 2011) and indigenous people can better respond to climate change (Nyong, 2007; Turner & Clifton, 2009; Yeh et al., 2014). The indigenous knowledge is also acknowledged for its crucial role in further advancing the understanding of scientific knowledge of climate change (Chaudhary & Bawa, 2011; Lead et al., 2005) and red panda conservation.With these understandings, building potential conservation interventions focusing coexistence of transhumance practice and red panda conservation could be biologically meaningful, the fact, however, has beeninadequately incorporated in previous studies.

The present study addressed the following questions:

1. How do transhumance herders perceive the impact of changes in climatic variables on the mutual co-existence of the livestock herds and red pandas?
2. What are the observed changes in biophysical indicators in red panda habitats?

Materials and Methods

Study Area

The research was conducted in the Barekot Rural Municipality (RM), Kuse RM,and Nalagad Municipality of Jajarkot District, Karnali Province, Nepal (Figure 1). Barekot and Kuse RM and Nalagad Municipality are homes to a total population of 74,425 (CBS, 2022). The seven adjoining fringe settlements close to the red panda habitat namely: Archanni and Paink of Kuse RM, Nayakwada, Rokayagaun and Sakala of Barekot RM and Ragda and Bhagawati of Nalagad Municipality were selected for primary data collection.

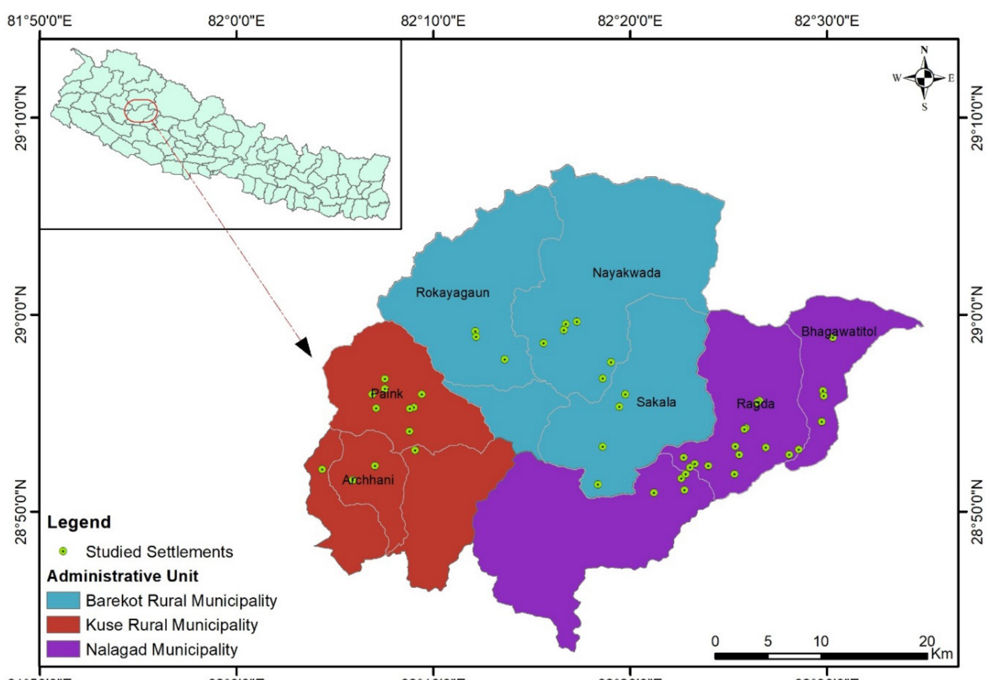


Figure 1. Map of the study area.

Human communities in the study area are mostly agro-pastoralists belonging to the Thakuri ethnic group. The traditional practice of transhumance, NTFPs collection (*Ophiocordyceps sinensis*, *Delphinium himalayai*, *Nardostachys jatamansi*, *Picrorhiza scrophulariiflora*, *Swertia chirayita*, *Paris polyphylla*, *Delphinium denudatum*, *Morchella esculenta*, *Ganoderma lucidum*, *Polygonatum cirrhifolium*, *Polygonatum verticillatum*, *Rheum australe*, *Valeriana jatamansii*, *Dactylorhiza hatagirea,etc.)* in red panda habitats contributes to the livelihoods of communities, relying mainly on subsistence agriculture with a strong linkage between farming, pasturelands, and forestry. Jajarkot is ranked as a district with a high ecological vulnerability index and a very high overall vulnerability to climate change (GoN, 2010). During the late spring and summer seasons livestock herders graze their livestock like *Bos Taurus, Bubalus bubalis,Equus ferus coballus*, *Equus asinus*, mules, *Capra aegagrus hircus*, and *Ovis aries* in the alpine pastures above their villages. Herders shift their herds among different pastures in the alpine region before bringing them down to the villages during winter. The study area beholds temperate,sub-alpine, alpine and nival types of vegetation and acts as a refuge for different mammal species such as *Ursus thibetanus*, *Ailurus fulgens*, *Semnopithecus schistaceus*, *Moschus spp*., *Muntiacus vaginalis*, *Hemitragus jemlahicus*, *Naemorhedus goral*, *Capricornis thar,* etc. (Baral, 2014; Baral et al., 2014).

Research Methods

The temperature and precipitation dataof the nearest meteorological stations were collected from the Department of Hydrology and Meteorology for trend analysis. Meteorological stations in Nagma, Musikot, Dipalgau, Jajarkot, Guthichaur and Dunai lies very close to those respective red panda habitats in Jajarkot. Therefore, the rainfall data during the last 37 years (1981-2017) and the temperature data during the last 27 years (1990-2016) in those stations were analyzed. The trends of the temperature and rainfall were calculated following the least square linear regression model (Wilks, 2011). Let x_1, x_2, x_3, ……x_n represent data points where represents the data point at time j. Then the linear equation of the data series is represented as:

$$y = mx + c \qquad \text{………………(i)}$$

where x represents the data series x_i for time i=1 to n and m gives magnitude of slope of the trend line. The positive value of m shows the increasing trend while the negative value gives the decreasing trend. The annual trends of temperature and rainfall were obtained using the data of all months (Shrestha &Aryal, 2011).

We adopted a qualitative research approach with in-depth face-to-face interviews (Babbie, 2007) to collect possible qualitative information about the impact of change in temperature and precipitation among agro-pastoralists in red panda habitats and its associated impacts on red panda. A total of 175 agro-pastoralists were purposively sampled and interviewed between September and December 2017. Seven focus group discussions (FGDs) containing a group of 5-8 agro-pastoralists per FGD were conducted in each study rural municipality and municipality. The likely impacts of climate change on the transhumance and red panda habitat were also discussed during the FGDs. The participants of in-depth and semi-directive interviews and FGDs were purposely selected to represent all geographical locations in the village and all categories of ethnicity, caste, class, and gender (Table 1). Participant observation was conducted in the research area by spending a total of forty days following daily herding activities and the potential risk of those activities on red pandas. The observations were noted in a diary, and important events were captured in photographs. The data collected through interviewees and FGDs were recorded using a voice recorder; they were then transcribed, translated, and analyzed using R (version4.1.2) and the Chi-Square test was performed to analyze the perception of herders on variables of climate change.

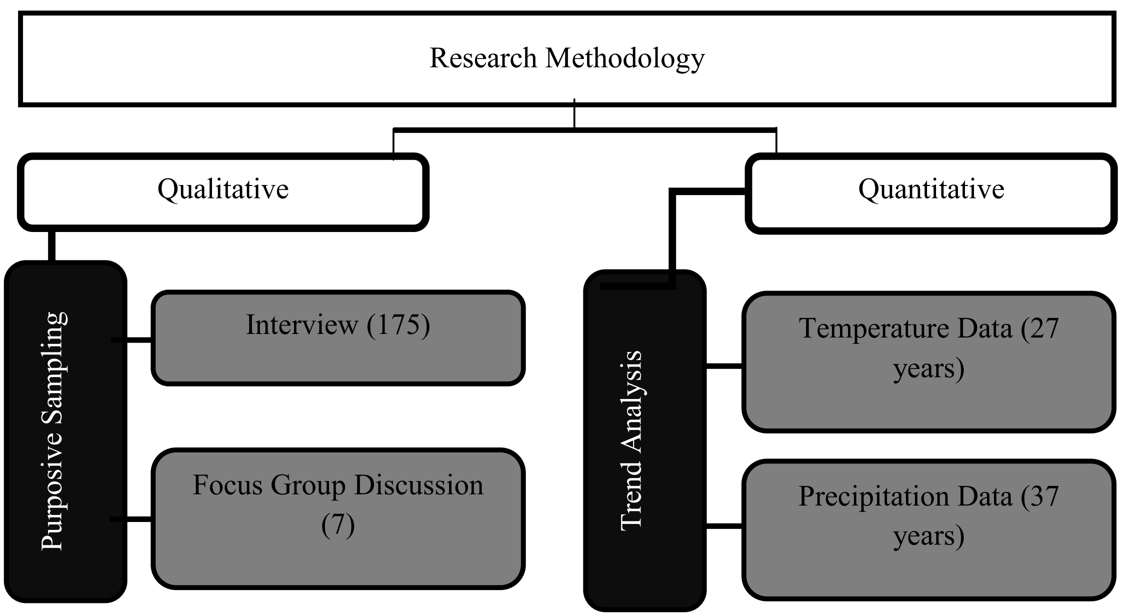


Figure 2: Methodological flow chart

Results and Discussion

Precipitation and Temperature change pattern analysis

The detailed analysis over a period of 37 years (1981-2017) reports that average annual precipitation is decreasing (Figure 3). The trend analysis showed a decrease in the average annual precipitation significantly over 37 years period with 6.2392 mm.

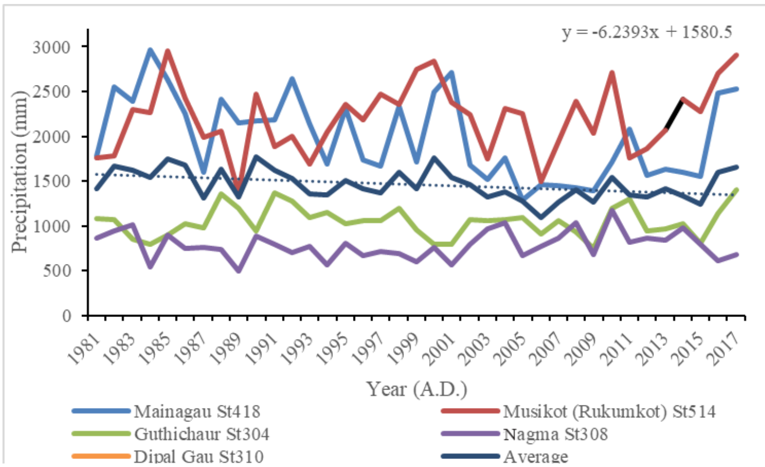


Figure 3: Precipitation trend analysis for five nearest stations to the study area from 1981-2017

The detailed analysis over a period of 27 years (1990-2016) reports that maximum and mean temperatures are decreasing. The trend analysis showed a decrease in the minimum, average and maximum temperature over 27 years period with 0.0332^{0}C, 0.0545^{0}C, and 0.0147^{0}C respectively.

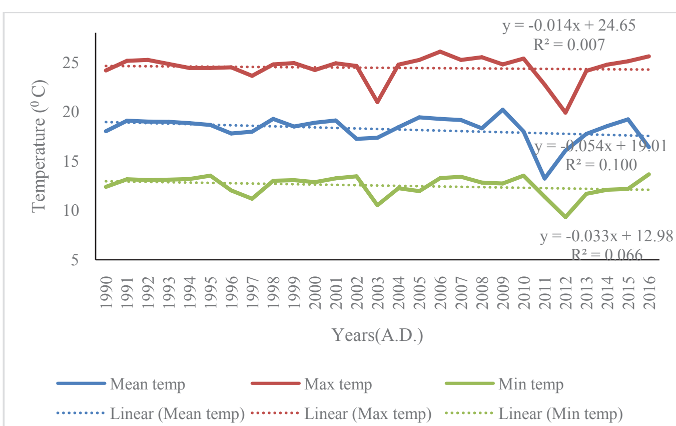
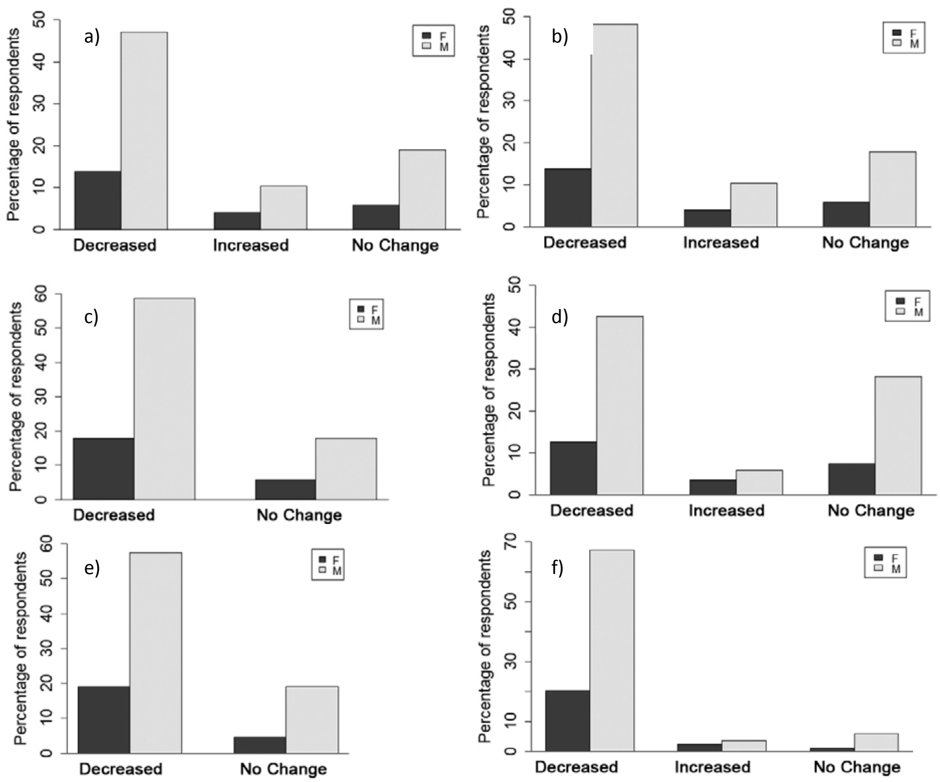


Figure 4: Temperature trend analysis for nearest station to the study area from 1990-2017

Perceived impacts of climate change

The impact of climate change on transhumant pastoralism and red panda habitat was reported by interviewees in different ways. The chi-squared test showed that there is no significant difference in the perception of transhumant herders on climate change based on gender (Table 1). According to 76.44% of respondents (57.47% Male and 18.97% Female), summer temperature is increasing and others 23.56% responded as no change. Whereas, according to 55.17% (42.53% Male and 12.64% Female), winter temperature is decreasing and remaining 28.16% responded as no change and few 5.75% as increasing. The total amount of annual rainfall, winter rainfall and monsoon rainfall are decreasing according to 60.92%, 76.44%and 62.07%respondents respectively. The total number of snowing days and the total amount of annual snowfall is also decreasing according to 97.7% and 87.35% of respondents respectively (Figure 5). This showed both male and



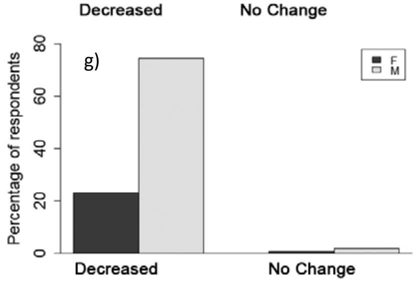
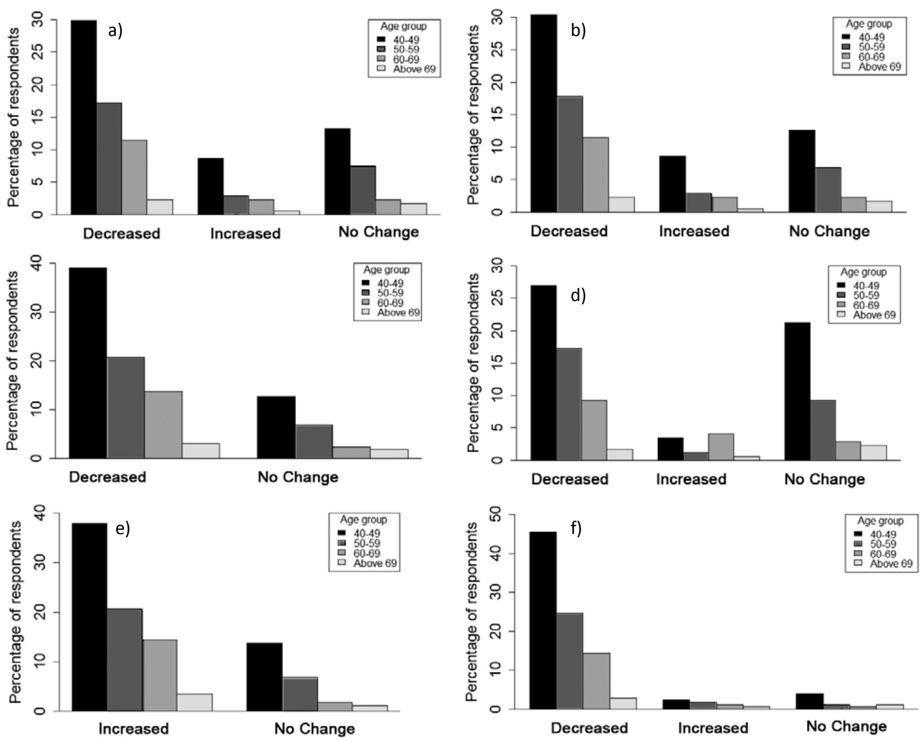


Figure 5: Perception of transhumant herders on a) amount of annual rainfall, b) monsoon rainfall, c) winter rainfall, d) winter temperature, e) summer temperature, f) annual snowfall and g) number of snowing days change based on gender

female perceive summer temperature is increasing whereas winter temperature, annual rainfall, winter rainfall, monsoon rainfall, number of snowing days and annual snowfall are decreasing in red panda habitat.

There is also no significant difference in the perception of transhumant herders on climate change variables based on age group (Table 1). According to 37.93%, 20.69%, 14.37% and 3.45% respondents of age group 40-49, 50-59, 60-69 and above 69 respectively, summer temperature is increasing. Maximum respondents of age group 40-49 (27.01%) and only fewer respondents of age group above 69 (1.72%) responded decrease in winter temperature. Maximum percentage of the respondents of age group 40-49 perceived total annual rainfall, winter rainfall and monsoon rainfall are decreasing. The total number of snowing days and the total amount of annual snowfall is also decreasing according to all age groups (Figure 6).



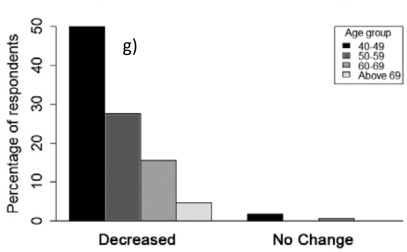


Figure 6: Perception of transhumant herders on a) amount of annual rainfall, b) monsoon rainfall, c) winter rainfall, d) winter temperature, e) summer temperature, f) annual snowfall and g) number of snowing days change based on age group

The chi-squared test showed that the perception of transhumant herders on the total amount of annual rainfall change and the total amount of monsoon rainfall change is significantly different with ($\chi^2 = 20.22$, $p < 0.01$) and ($\chi^2 = 20.33$, $p < 0.01$) respectively based on education. All the respondents having bachelor level of education responded increase in the total amount of annual rainfall and the total amount of monsoon rainfall but the maximum respondent perceived decrease in it. Perception on all other variables of climate change is not significantly different based on education level. Maximum percentage of respondent 76.43% perceived increase in summer temperature (Bachelor: 2.87%, Illiterate: 22.41%, Literate: 17.82%, Primary: 20.11% and Secondary: 13.22%) and 56.16% (Bachelor: 0.57%, Illiterate: 16.09%, Literate: 15.52%, Primary: 12.64% and Secondary: 10.34%) perceived decrease in winter temperature based on education level. Total number of snowing days and total amount of annual snowfall is also decreasing according to 97.7% (Bachelor:2.87%, Illiterate: 28.16%, Literate: 21.84%, Primary: 25.86% and Secondary: 18.97%) and 87.35% (Bachelor: 2.87%, Illiterate: 25.29%, Literate: 20.11%, Primary: 22.41% and Secondary: 16.67%) of the respondents respectively (Figure 7).

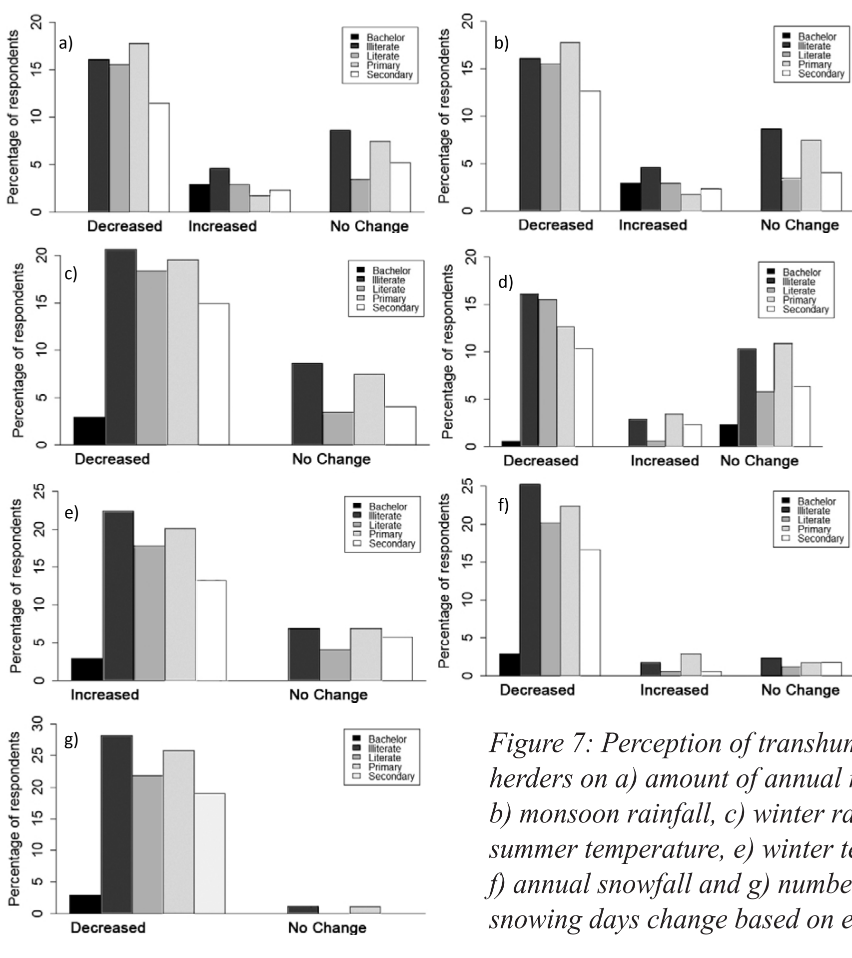


Figure 7: Perception of transhumant herders on a) amount of annual rainfall, b) monsoon rainfall, c) winter rainfall, d) summer temperature, e) winter temperature, f) annual snowfall and g) number of snowing days change based on education

The Chi-square test showed that there is a significant difference in the perception of transhumant herders on change in winter temperature based on duration of time spend in corrals with ($\chi^2 = 13.07$, $p = 0.01$) (Table 1). The 55.18% of the respondents who spend (1-4 years: 10.92%, 4-8: 28.74%, above 8: 15.52%) perceived a decrease in winter temperature while the other 9.19% perceived an increase, and 35.64% perceived no change. Perception on all other variables of climate change is not significantly different (Table 1).

Table 1:Chi-squared test on the perception of transhumant herders on variables of climate change (Significant values are shown in bold).

Perception of transhumant herders on climate change	Based on gender (df = 1 and 2)		Based on age group (df = 3 and 6)		Based on education (df = 4 and 8)		Based on duration spend in corrals (df = 2 and 4)	
Change in	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value
Summer temperature	0.06	0.80	1.79	0.62	1.74	0.78	4.39	0.11
Winter temperature	1.14	0.57	8.34	0.21	6.16	0.63	**13.07**	**0.01**
Total amount of annual rainfall	0.19	0.91	2.07	0.91	**20.22**	**< 0.01**	9.15	0.05
Total amount of winter rainfall	0.00	1	1.32	0.72	2.49	0.65	1.97	0.37
Total amount of monsoon rainfall	0.23	0.89	1.96	0.92	**20.33**	**< 0.01**	6.84	0.14
Total number of snowing days	0.00	1	1.12	0.77	1.83	0.77	3.65	0.16
Total amount of annual snowfall	1.06	0.59	3.73	0.71	2.54	0.96	3.70	0.45

All herder interviewees reported that in recent years the snowfall pattern had been erratic. The amount of snow was decreasing, and the accumulated snow was melting earlier than in the past with its repercussion effect of drying of streams earlier. The herders observed the decrease in the thickness of snow in many Kharkas (pasturelands), scarcity of water in traditional water sources such as streams and ponds along the livestock migration routes within red panda habitats.

As described by one of the leading herders in the Barekot region:

In the past red pandas' habitats used to be less disturbed because we used to graze our livestock many days in a single Kharka, now we have to move to many Kharkas and our herds reach every good habitat of the red panda to find nutritious grasses. Due to the scarcity of water, we have to change our travel route and locations of overnight camps these days, so does red panda change and its activity concentrate close to these limited water resources.

One of the respondents in the Kuse region reported that the forests and pasture invasion by non-palatable invasive weed as a climate-driven effect related to increasing temperature and the suppression of regeneration of undergrowth vegetation in the forests and pasture lands induced by erratic rainfall pattern with an impact on livestock grazing. As reported by herder respondents:

All the farmlands, forests and pasture lands are now covered by Banmara *(Eupatorium sp., a non-palatable invasive weed),* Nilo gandhejhar *(Ageratum sp., an invasive weed)*. These non-palatable invasive weeds suppress the regeneration of undergrowth vegetation in the forests and pasture lands causing a decline in other palatable grasses from Kharkas. So, we don't have enough grasses now.

Another interviewee from the Nalagad region described the increase in livestock diseases and the use of medicines against livestock diseases in recent years in their view to the changing climate. As reported by a herder interviewee:

These days our cattle started suffering from Namle (foot-and-mouth disease) which has become quite common, a disease we had never experienced before. Now we have experienced many livestock deaths in our Kharkas due to this disease. In the winter many goats and sheep are dying due to pneumonia. We mostly live far from the service centers and don't get any veterinary support in these Kharkas.

The transhumance system is a means of livelihood, adaptive strategy as well as a matter of indigenous practice and cultural significance.However, due to the impacts of socioeconomic and environmental changes, the practice is gradually declining towards extinction in the mountains of Nepal (Gentle &Thwaites, 2016). A similar trend has been reported from the study area.

The majority of the transhumant herders have observed the early onset of the summer season, rapid melting of snow, early induce in greenery, and early flowering/maturing of vegetation and appearance of new plant species in the red panda habitat. Species Distribution Modelillustrated that the red pandahad a strong responseto precipitation-associated bioclimatic variables in the Himalayas, particularly annual precipitation, precipitation in the coldest quarter, precipitation seasonality, and precipitation in the driest month (Thapa et al., 2018). But in this study erratic snowfall, a decrease in the amount of snow, and early melting of accumulated snow than in the past have been reported hence could influence red panda distribution in the future.

The temperature and precipitation largely predict habitat suitability at a landscape level and are key components in shaping the vegetation composition of the red panda habitat (Thapa et al., 2018). Most of the herders in this study perceived summer temperature is increasing whereas winter temperature, annual rainfall, winter rainfall, monsoon rainfall, the number of snowing days, and annual snowfall are decreasing in red panda habitat. Climate-associated variables provide basic information on suitable habitat for the species and are considered the most important determinant of species occurrence (Pearson & Dawson, 2003). High precipitation implies increased cloud cover, leading to a significant reduction in soil temperature, reduced radiation input and high cloud albedo (Takahashi et al., 2005) resulting in delayed soil warming in spring, reduced tree growth, and slow understory regeneration. Temperature and precipitation have a great influence over the growth rates of bamboo understories (Rao et al., 1991), a dietary staple for red pandas (Zhang et al., 2009; Pradhan et al., 2001; Wei et al., 1999; and Yonzon,1989). Hence, the changes in climatic variables like temperature and precipitation in rangelands could haveadverse effects like alteration of competition between plants and their growth habits, plant-animal interaction, productivity (IPCC, 2014). The drying of water resources can lead to the abandonment of rangelands which in turn can lead to grazing pressure in other rangelands (Aryal, 2015) and similar observations have been made in this study too.

As they directly depend upon nature and natural resources,the transhumance herders across the mountainsare disproportionately more vulnerable due to climate change (Aryal et al., 2014; Dong, 2011) and the situation could be even more severe when the flexibility of herders is restricted (Fu et al., 2012), so do thosefrom Jajarkot. The drying of water resources, increase in drought, and appearance of new livestock diseases were also perceived by transhumant herders. These observations are in line with the findings of previous scholars (Shrestha et al., 2012; Lama &Devkota, 2009; Xu et al., 2009; Aryal et al., 2014; Gentle&Thwaites, 2016) who have reported advancing growing season and change in the phenology of the vegetation in the Himalayas. Aryal (2015) indicated drying of water resources in the rangeland and the results of the Kuse also correspond to them. There were a very less proportion of herders who agreed that grassland zones are shifting. This particular observation of herders is not in line with another study (Gaire et al., 2014) that report a shift of range for many plant species, tree line and vegetation belt. A slow and gradual process of vegetation shift may be responsible for the differential response of herders.

Loss of native species in the pasture-induced gradual degradation in vegetation has been reported which is in line with Parajuli et al., (2013). There was a large proportion of respondents who agreed that non-native and unpalatable invasive alien species have appeared in the red panda habitats. The appearances of those species indicate the poor quality of rangelands and ultimately affect livestock production in the study area. Invasive alien species disrupt the ecology of the natural ecosystem, displace the native plant and animal species as well as degrade the landscapes unique and diverse biological resources (Tiwari et al., 2005). The increase of such unwanted species can be related to an increase in temperature and associated range shift (Gaire et al., 2014) or an increase in drought, cessation of fire and range abandonment (Brandt et al., 2013). In the study site, it has been reported that livestock are more susceptible to increasing incidences of diseases like foot and mouth diseases and pneumonia. This increase in the incidence of diseases causing vectors may be related to change in climatic variables which largely determine their population dynamics and distribution range (Gage et al., 2008; Aryal, 2015).

Conclusion

Observations of transhumance herders' perceptions on climatic variables in red panda habitats of Jajarkot can complement modern conservation sciences, offer some clues about climate change, and associated livelihoods to reduce vulnerability to its impact by building adaptive capacity and resilience; and facilitate the integration of climate change and coherently, into relevant new and existing policies, programmes and activities, in particular development planning processes and strategies, within all relevant sectors and at different levels, as appropriate.Concomitantly, the herding, a relatively secured livelihoods strategy of people residing nearby red panda habitats, hasbeen threatened with several socio-cultural, economic and ecological consequences. Hence, these sorts of research avenues can act as an important filter to inform government and other relevant actors to offer appropriate policy and programmatic support, strategic decisions for three core interwoven components: biodiversity conservation, sustainable landscapes and livelihood policies.

Acknowledgments

We acknowledge the contribution of local communities and herders at the research site for their responses, opinions, support, and knowledge contribution during the field visits. Their insights provided depth and clarity to our study. This research has been co-financed by Nature Conservation Initiative Nepal (NCI-Nepal) and Nepal Environmental Research Institute (NERI) Nepal.Our special thanks go to the Department of Hydrology and Meteorology of the GoN for providing us with temperature and precipitation data.

References

- Agrawal, A. (2010). Local institutions and adaptation to climate change. In: Mearns R, Norton A, editors. *Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World*. Washington DC: World Bank.

- Alexander, C., Bynum, N., Johnson, E., King, U., Mustonen, T., Neofotis, P., Oettlé, N.,Rosenzweig, C., Sakakibara, C., Shadrin, V., Vicarelli, M., Waterhouse, J. & Weeks, B. (2011). Linking indigenous and scientific knowledge of climate change. *BioScience* 61: 477-484.

- Aryal, S. (2015). The socio-ecological impacts of structural changes in the transhumance system of the mountainous area of Nepal. PhD Thesis, University of Southern Queensland Australia.

- Aryal, S., Maraseni, T.N. &Cockfield, G. (2014). Sustainability of transhumance grazing systems under socio-economic threats in Langtang, Nepal. *Journal of Mountain Science* 14(4):1023-1034.

- Babbie, E.R. (2007). *The Practice of Social Research*. 11th edition. Belmont, CA: Thomson Higher Education.

- Baral, B. (2014). Baseline study of red panda (*Ailurus fulgens fulgens*, Cuvier 1825) in Jajarkot district, Mid-Western Nepal. Master Thesis (unpublished), Tribhuvan University, Nepal.

- Baral, H.S., Shah, K.B., Adhikari, S. & Paudel, R. (2014). Feasibility study for community-based wildlife conservation for livelihoods diversification in Nepal: a case study from Barekot area of Jajarkot district. Kathmandu, Nepal: Multi-Stakeholder Forestry Programme, Ministry of Forests and Soil Conservation, Government of Nepal.

- Bradie, J. &Leung, B. (2017). A quantitative synthesis of the importance of variables used in MaxEnt species distribution models. *Journal of Biogeography* 44:1344-1361.

- Brandt, J.S., Haynes, M.A., Kuemmerle, T., Waller, D.M. &Radeloff, V.C. (2013). Regime shift on the roof of the world: Alpine meadows converting to shrublands in the southern Himalayas. *Biological Conservation* 158: 116-127.

- CBS (2022). National Census Report: Preliminary Result. National Planning Commission, Central Bureau of Statistics, Thapathali, Kathmandu.

- Chaudhary, P. &Bawa K.S. (2011). Local perceptions of climate change validated by scientific evidence in the Himalayas. *Biology Letters* 7: 767-770.

- Dong, S., Wen, L., Liu, S., Zhang, X., Lassoie, J.P., Yi, S., Li, X., Li, J.&Li, Y. (2011). Vulnerability of Worldwide Pastoralism to Global Changes and Interdisciplinary Strategies for Sustainable Pastoralism. *Ecology and Society*16:2-10.

- Dorji, S., Rajaratnam, R. &Vernes, K. (2012). The Vulnerable red panda *Ailurus fulgens* in Bhutan: distribution, conservation status and management recommendations. *Oryx* 46:536-543.

- Fu, Y., Grumbine, R., Wilkes, A., Wang, Y., Xu, J.C.&Yang, Y.P. (2012). Climate Change Adaptation among Tibetan Pastoralists: Challenges in Enhancing Local Adaptation through Policy Support. *Environmental Management* 50(4): 607-621.

- Gage, K. L., Burkot, T.R., Eisen, R.J. &Hayes, E.B. (2008). Climate and vectorborne diseases. *American Journal of Preventive Medicine* 35**:** 436-450.

- Gaire, N., Koirala, M., Bhuju, D. &Borgaonkar, H. (2014). Treeline dynamics with climate change at the central Nepal Himalaya. *Climate of the Past* 10:1277-1290.

- Gentle, P. &Thwaites, R. (2016). Transhumant Pastoralism in the Context of Socioeconomic and Climate Change in the Mountains of Nepal. *Mountain Research and Development* 36(2):173-182.

- Glatston, A.R. (1994). *Status survey and conservation action plan for procyonids and ailurids: The red panda, olingos, coatis, raccoons and their relatives*. Gland, Switzerland: IUCN.

- Glatston, A.R., Wei, F., Than, Z., Sherpa, A. (2015). *Ailurus fulgens. The IUCN Red List of threatened species 2015*: e.T714A110023718. Retrieved from https://doi.org/10.2305/iucn.uk.2015-4.rlts.t714a45195924.en Downloaded on 18 December 2017.

- GoN/MoFSC. (2014). Nepal Biodiversity Strategy and Action Plan 2014-2020. Government of Nepal/ Ministry of Forests and Soil Conservation, Kathmandu, Nepal.

- Government of Nepal (GoN) (2010). *National Adaptation Programme of Action (NAPA)*. Kathmandu, Nepal: Ministry of Environment, Government of Nepal.

- Government of Nepal (GoN) (2010). *National Population and Housing Census*

2011 (National Report). Kathmandu, Nepal: National Planning Commission, Central Bureau of Statistics, Government of Nepal.

- Huntington, H.P. (1998). Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge. *Arctic* 51:237-242.

- Hunzai, K., Gerlitz, J., Hoermann, B. (2011). *Understanding Mountain Poverty in the Hindu Kush-Himalayas: Regional Report for Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan*. Kathmandu, Nepal: International Centre for Integrated Mountain Development.

- IPCC. (2007). Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

- IPCC. (2014). Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and Sectoral Aspects.Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

- IPCC (2019). Special Report on the Ocean and Cryosphere in a Changing Climate https://www.ipcc.ch/report/srocc/ .

- Kandel, K., Huettmann, F., Suwal, M.K., Regmi, G.R., Nijman. V., Nekaris, K.A.I., Lama, S.T.,Thapa, A., Sharma, H.P. &Subedi, T.R. (2015). Rapid multi-nation distribution assessment of a charismatic conservation species using open-access ensemble model GIS predictions: Red panda (*Ailurus fulgens*) in the Hindu-Kush Himalaya region. *Biological Conservation* 181:150-161.

- Lama, S., &Devkota. B. (2009). Vulnerability of mountain communities to climate change and adaptation strategies. *Journal of Agriculture and Environment* 10: 76-83.

- Lead, C., Nelson, G.C. &Bennett, E. (2005). Drivers of change in ecosystem condition and services. Ecosystems and Human Well-Being: Scenarios: Findings of the Scenarios Working Group 2**:** 173.

- Miller, D. (1995). *Herds on the Move: Winds of Change among Pastoralists in the Himalayas and on the Tibetan Plateau*. Kathmandu, Nepal: International Centre for Integrated Mountain Development.

- Morelle, K. &Lejeune, P. (2015). Seasonal variations of wild boar *Sus* *scrofa* distribution in agricultural landscapes: A species distribution modeling approach. *European Journal of Wildlife Research* 61:45-56.

- Ning, W., Rawat, S.G. &Sharma, E. (2013). High-Altitude Ecosystem Interfaces in the Hindu Kush Himalayan Region. International Center for Integrated Mountain Development, Kathmandu, Nepal.
- Nyong, A., Adesina, F. & Elasha, B.O. (2007). The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitigation and Adaptation Strategies for Global Change* 12: 787-97.
- Pandey, M.R. &Chhetri, M. (2005). Nomads and Pastoralism: Linkage with Biodiversity Conservation in Upper Mustang, Nepal. *Our Nature* 3:42-49.
- Parajuli, D.P., Paudel, L.N. &Gyawali, R.R. (2013). Changes in Pastoral Production Systems in High-Altitude Village-Rangeland Interfaces in Nepal. Special Issue, 30, International Center for Integrated Mountain Development, Kathmandu, Nepal.
- Pearson, R.G.A. & Dawson, T.P. (2003). Predicting the impacts of climate change on the distribution of species: Are bioclimate envelope models useful? *Global Ecology and Biogeography* 12:361-371
- Petheram, L., Zander, K., Campbell, B., High, C., &Stacey, N. (2010). Strange changes: Indigenous perspectives of climate change and adaptation in NE Arnhem Land (Australia). *Global Environmental Change* 20: 681-92.
- Pradhan, S., Saha, G.K. &Khan, J.A. (2001). Ecology of the red panda *Ailurus fulgens* in the Singhalila National Park, Darjeeling, India. *Biological Conservation* 98:11-18.
- Rao, A.N., Zhang, X.P., &Zhu, S.L. (1991). Selected papers on recent bamboo research in China. Beijing, China: Bamboo Information Centre, Chinese Academy of Forestry.
- Roberts, M.S., Gittleman, J. L. (1984). *Ailurus fulgens*. *Mammalian Species* 222:1-8.
- Rota, A., Sperandini, S. (2010). *Livestock and Pastoralists*. IFAD Livestock Thematic Papers Tools for Project Design. Rome, Italy: International Fund for Agricultural Development (IFAD).
- Sánchez-Cortés, M.S., Chavero E.L. (2011). Indigenous perception of changes in

climate variability and its relationship with agriculture in a Zoque community of Chiapas, Mexico. *Climatic Change*107: 363-89.

- Sharma, H.P. & Belant, J.L. (2009). Distribution and observations of red pandas (*Ailurus fulgens fulgens*) in Dhorpatan Hunting Reserve, Nepal. *Small Carnivore Conservation* 40:33-35.

- Shrestha, A.B. &Aryal, R. (2011). Climate change in Nepal and its impact on Himalayan glaciers. *Regional Environmental Change* 11:65-77.

- Shrestha, U.B., Gautam, S. & Bawa, K.S. (2012). Widespread Climate Change in the Himalayas and Associated Changes in Local Ecosystems. *PLoS ONE* 7(5): e36741. https://doi.org/10.1371/journal.pone.0036741

- Takahashi, K., Tokumitsu, Y. &Yasue, K. (2005). Climatic factors affecting the tree-ring width of *Betula ermanii* at the timberline on Mount Norikura, central Japan. *Ecological Research* 20: 445-451.

- Thapa, A., Wu, R., Hu, Y., Nie, Y.G., Singh, P.B., Khatiwada, J.R., Yan, L., Gu, X. & Wei, F. (2018). Predicting the potential distribution of the endangered red panda across its entire range using MaxEnt modeling. *Ecology and Evolution.*

- Tiwari, S., Adhikari, B., Siwakoti&M., Subedi, K. (2005). An Inventory and Assessment of Invasive Alien Plant Species of Nepal. Kathmandu, Nepal: IUCN-The World Conservation Union, Nepal.

- Tremblay, J.C. & Ainslie, P.N.(2021). Global and country-level estimates of human population at high altitude. *Proceedings of the National Academy of Sciences of the United States of America* 118(18): e2102463118.

- Turner, N.J. &Clifton, H. (2009). "It's so different today": Climate change and indigenous lifeways in British Columbia, Canada. *Global Environmental Change* 19:180-190.

- Viviroli, D., Archer, D. R., Buytaert, W., Fowler, H. J., Greenwood, G. B., Hamlet, A. F., Huang, Y., Koboltschnig, G., Litaor, M. I., López-Moreno, J. I., Lorentz, S., Schädler, B., Schreier, H., Schwaiger, K., Vuille, M.&Woods, R. (2011): Climate change and mountain water resources: overview and recommendations for research, management and policy. Hydrology and Earth System Science 15: 471-504, https://doi.org/10.5194/hess-15-471-2011.

- Wang, T.J., Ye, X.P., Skidmore, A.K., &Toxopeus, A.G. (2010). Characterizing the spatial distribution of giant pandas (*Ailuropoda melanoleuca*) in fragmented forest landscapes. *Journal of Biogeography* 37:865-878.

- Wei, F.W., Feng, Z., Wang, Z., Zhou, A. &Hu, J. (1999). Use of the nutrients in bamboo by the red panda (*Ailurus fulgens*). *Journal of Zoology* 248:535-541.
- Wilks, D.S. (2011). *Statistical Methods in the Atmospheric Sciences*. 3rd ed. Academic Press, 676 pp.
- Wilson, R.J., Gutierrez, D., Gutierrez, J. &Monserrat, V.J. (2007). An elevational shift in butterfly species richness and composition accompanying recent climate change. *Global Change Biology* 13**:**1873-1887.
- Xu, J., Grumbine, R.E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y. & Wilkes, A. (2009). The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. *Conservation Biology* 23:520-530.
- Yeh E.T., Nyima Y, Hopping K.A.&Klein J.A. (2014). Tibetan Pastoralists' Vulnerability to Climate Change: A Political Ecology Analysis of Snowstorm Coping Capacity. *Human Ecology* 42:61-74.
- Yonzon, P.B. (1989). Ecology and conservation of the red panda in the Nepal-Himalaya Ph.D. Thesis, University of Maine, Orono, ME.
- Yonzon, P.B.&Hunter M.L.(1991). Conservation of the red panda *Ailurus fulgen*s. *Biological Conservation* 57:1-11
- Yonzon, P., Yonzon, P., Chaudhary, C. &Vaidya B. (1997). *Status of the red panda in the Himalayas*. Kathmandu, Nepal: Resources Nepal.
- Zhang, Z.J., Hu, J.C., Yang, J.D., Li, M. & Wei, F.W. (2009). Food habits and space-use of red pandas *Ailurus fulgens* in the Fengtongzhai Nature Reserve, China: Food effects and behavioural responses. *Acta Theriologica* 54:225-234.

Extract of Lyonia ovalifolia (Wall.) Drude as a Potent Rodenticide

Sabin Shakya[1]*, Sushma. Upadhayay[2], Dr. Bhupendra Devkota[1]
[1]College of Applied Sciences-Nepal
[2]Former Deputy Director General at Department of Plant Resources, Thapathali
*Corresponding email: sabin_shkya@yahoo.com

Abstract

Phytochemicals are naturally synthesized in all parts of the plant body. Lyonia ovaliafolia (Wallich) has been used in a traditional medicine for the treatment of skin diseases such as scabies and itching by different local communities of Nepal. The study was done to analyze the active phytochemicals present in alcoholic extract of its leaves. The sample was random collection along the road, from Namobuddha. A range of chemical tests were adopted for analyzing the types of phytochemical compounds and toxicity test based on OECD guideline.

The results showed that the active phytochemicals present were saponin, flavonoids, tannin, steroids and cardiac glycosides in adequate amount. The toxicity present in the leaves finds scope to be experimented as botanical pesticides in agriculture farm as an alternative of chemical rodenticides.

Keywords: *phytochemicals, toxicity, extract*

Introduction

Phytochemicals are naturally synthesized in all parts of the plant body such as bark, leaves, stem, root, flower, fruits, seeds, etc. (Ugochukwu et al., 2013). These phytochemicals are non-nutritive plant chemicals but have protective or disease preventive properties. Plant produces these chemicals to protect itself where studies demonstrate that many phytochemicals can also protect humans against diseases (Poongothai et al., 2011). The quantity and quality of phytochemicals present in plant parts may differ from one part to another (reference needed). Phytochemicals have been recognized as the basis for traditional herbal medicine practiced in the past and currently in different parts of the world (Ugochukwu et al., 2013) and are involved in plants defense against aggression by pathogens. *Lyonia ovalifolia*, a member of the genus *Lyonia* belonging to Ericaceae family, has tannins, saponins, steroids, flavonoids, and cardiac glycosides and show antibacterial activities against bacterial pathogens (Negi et al., 2012 as cited in Acharya et al., 2014). *Lyonia ovalifolia* (anger) is deciduous tree. *L. ovalifolia* grows at an altitude of about 1300-3300 masl in Nepal. The flowering period of *L. ovalifolia* is May to June and fruiting period is July to September (Fang & Stevens, 2005).

According to the farmers, newly sprouted leaves and buds are poisonous to animals such as young goats but in humans, the leaf juice is applied to treat scabies and itching (Manandhar, 2002). *L. ovaliafolia* (Wallich) has been used in a folk medicine for the treatment of wounds, cuts, burns, scabies, etc. by different local communities of Nepal (Acharya et al., 2014). This might be because of defensive mechanism of the plants by the production of secondary metabolites. The use of this plant can be beneficial in antibacterial activities. This planthas not yet been researched as pesticides, only it is known to have toxic effect on the animals (young goats). If the young leaves of the plant are really found to be toxic then the plant might be used as an alternative the chemical pesticide. Ministry of Agriculture and Livestock Development has been researching in the alternatives of the chemical pesticides because of its negative impacts in human as well as animal health, the degradation in environmental quality, reduction of soil fertility as well as banning and reducing the use of chemical pesticides and encouraging the use of different biological pesticides (G.C. 2015) so, this study might provide a way for a new generation of biological pesticides. Hence, this study is performed to study the toxicity level of the leaves and to test the leaves as an alternative of chemical rodenticide.

Materials and Methods

Study Area

The study was carried in Namobuddha. It lies in Kavrepalanchowk District and about 40km South East from the Kathmandu.

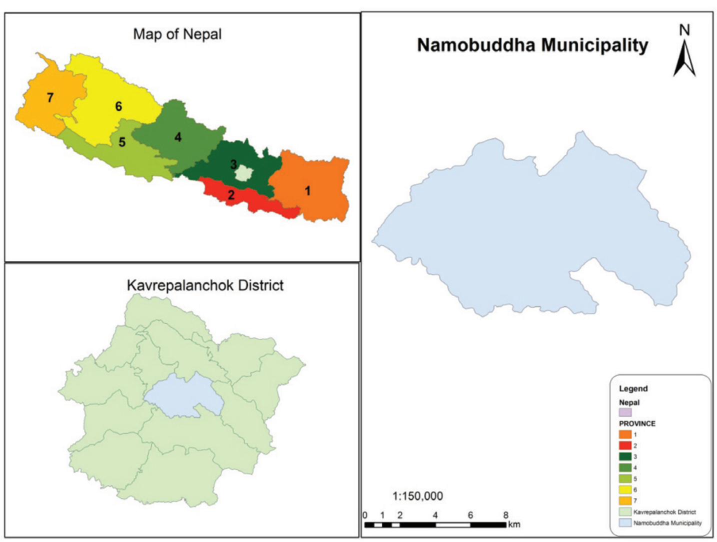


Figure 1: Study Area

Figure 2: Google Map of Study Area (Accessed on 2016)

Sample Collection and Identification

A random collection of young leaves were done in the month of March 2016 and identified as *L. ovalifolia* in National Herbarium and Plant Laboratories, Kathmandu.

Method of Extraction

The collected leaves were air-dried at room temperature under shade and grinded into fine powder. About 40 gms of the powder was taken in the percolator. It was filled with equal amount of distilled water and alcohol. The apparatus was allowed to settle. After an hour, it was shaken and kept for 24 hours. The solution was then poured in the beaker and was dried in water-bath.

Method of Treatment

1. Phytochemical Screening: Different processes were adopted for analyzing the types of phytochemical compound groups that are present in the leaves. The process adopted for the screening is shown below:

S.N.	Chemical Test	Process
1.	Test for Proteins (Millon's test)	3 ml extracts + 5 ml Million's reagent = White ppt. + warm ppt. = Brick red or the ppt. dissolves giving red colored solution (Ugochukwu et al., 2013).
2.	Test for Carbohydrates (Fehling's test)	(Fehling A + Fehling B reagents) + Few drop of extract + Boiled = Brick red colored precipitate (Joseph et al., 2013).
3.	Test for Phenols	Crude extract (500mg) + 5 ml of distilled water + Few drops of neutral 5% ferric chloride solution = Dark green color (Ahmad et al., 2013)
4.	Test for Saponins (Foam test)	Crude extract (500mg) + 5 ml of distilled water + Shaken vigorously = Formation of stable persistent foam (Kavishankar et al., 2011)
5.	Test for Tannins	Extract (2 ml) + 10% alcoholic $FeCl_3$ solution = Formation of blue or greenish color solution (Ugochukwu et al., 2013).
6.	Test for Steroids	Extract (1 ml) + Few drops of chloroform + acetic anhydride + conc. H_2SO_4 = Formation of dark pink or red colour (Ugochukwu et al., 2013).
7.	Test for Terpenoids	Extract (2 ml) + 1 ml of chloroform + Few drops of conc. H_2SO_4 = Reddish brown precipitate (Ugochukwu et al., 2013).
8.	Test for Flavonoids (Alkaline Reagent test)	Extract (2 ml) + Few drops of NaOH solution = Formation of intense yellow color + few drops of dilute HCl = Colorless (Minj et al., 2017).
9.	Test for Cardiac Glycosides (Keller kiliani Test):	Extract (2 ml) + 1 ml glacial acetic acid + Few drop 5% FeCl3 + 1 ml conc. H_2SO_4 = Brown ring on the interface (Minj et al., 2017).
10.	Test for Alkaloids	Extract (2 ml) + 1 ml of 1% HCl + heat gently + Few drops of Mayer's reagent and Wagner's reagent = Turbidity (Minj et al., 2017).

Toxicity: OECD Guideline (2001) for Testing of Chemicals (Acute Oral Toxicity Up and Down Procedure) was adopted for the test of toxicity. This method involves the sequential dosing of single animals (Swiss Albino Mice) with the test substance within a time interval of 48 hours. After the administration of the first dose, the next is determined by the outcome of the subsequent dose administered. If the animal survives the subsequent dose, the dose is adjusted upward, but when mortality is recorded at subsequent dose, it is adjusted downward. The adjustment of dose either upward or downward is by a constant factor. Testing is terminated when the upper limit (2000-5000 mg/kg) have been reached without mortality or when the LD_{50} have been established from the test.

Acute Oral Toxicity Up and Down Procedure was divided into stages, with the outcome from each stage determine the next step to take (i.e., whether to terminate or proceed to the next stage).

i. Stage 1: This stage requires four animals (Swiss Albino Mice). These animals are divided into four groups of one animal each where the animals should be observed for 1 hours post-administration and then 10 minutes every 2 hours interval for about 24 hours. The behavioral signs of toxicity and also mortality should be recorded. Where no mortality is recorded at this stage, the testing should proceed to stage 2.

ii. Stage 2: This stage involves three animals, which are divided into three groups of one animal each. Different doses of the test substance (higher than those used in stage 1) are administered to the different animals and then observed for 1 hour after administration and periodically for 24 hours. Behavioral signs of toxicity and mortality should be noted. If no mortality occurred, testing should proceed to stage 3.

iii. Stage 3: This stage requires five animals. Various high doses of test substance (with 5000 mg/kg as the highest) are administered to the test animals. Observation is done for 1 hour after administration and then 10 minutes every 2 hours for 24 hours. Behavioral toxicity signs and also mortality should be recorded. This is the final stage of testing and where no mortality is recorded at this stage, the LD_{50} of the test substance is said to be greater than 5000 mg/kg and hence has a high degree of safety.

Initially the main test was performed for each sample assuming the sample was likely to be toxic. While testing the extract the test animal was kept fasting for 24 hours. The test animals weren't fed for 24 hours except water.

Calculation of the dose

Dose calculation is based on the OECD (2001). If 20gm test animal (Swiss Albino Mice) is to be given 175mg/kg then:

=175mg/kg

=1.75mg/10gm

=3.5mg/20gm

So, 3.5mg of the extract should be given to 20gm. Mice. Hence, 3.5gm of the extract should be dissolved in l ml and 0.2 ml should be fed.

Results and Discussion

Phytochemical Screening

During the study, the color was observed for the confirmation of the presence of the phytochemicals. The dark color shows the presence of phytochemicals was adequate amount and light color shows the trace amount. Saponin, steroids, flavonoids, cardiac glycosides and tannins were present in adequate amount in the leaves of *Lyonia ovalifolia*. Acharya *et al.* (2014) studied the antioxidant and antimicrobial properties of Leaves *L. ovalifolia*. Also, studied phytochemicals present in the leaves using different extracts; alkaloids was found in appreciable amount in chloroform extract; tannins, phenols, carbohydrates & glycosides in appreciable amount and alkaloids in trace amount in ethanol extract. The difference in the phytochemicals might be due to the types of solvent used i.e. use of polar and nonpolar solvent in the extraction of the leaves. It showed that some of the chemicals in the plants are nonpolar.

Toxicity

Swiss albino mice were kept fasting for 24 hours (water was provided) and next day different doses were fed and observed for 48 hours. Since none of the mice died in the low concentration of the dose of the extract. The dose was increased to maximum following OECD (2021) until the dose was fatal.

Table 1: Toxicity Test of leaves of L. ovalifolia

S.N.	Dose (mg/kg)	Weight of Mice (gm.)	Results
1	175 mg/kg	27 gm.	Non-Lethal
2	550 mg/kg	25 gm.	Non-Lethal
3	1750 mg/kg	29 gm.	Non-Lethal
4	2300 mg/kg	26 gm.	Non-Lethal
5	2400 mg/kg	31 gm.	Non-Lethal
6	2600 mg/kg	28 gm.	Non-Lethal
7	2750 mg/kg	30 gm.	Non-Lethal
8	3100 mg/kg	27 gm.	Non-Lethal
9	3400 mg/kg	25 gm.	Non-Lethal
10	3750 mg/kg	27 gm.	Non-Lethal
11	4100 mg/kg	30 gm.	Lethal
12	5000 mg/kg	29 gm.	Lethal

Table 2: Confirmation of Toxicity

S.N.	Dose (mg/kg)	Weight of Mice (gm.)	Results
1	3750 mg/kg	35 gm.	Non-lethal
2	3750 mg/kg	32 gm.	Lethal
3	3750 mg/kg	34 gm.	Lethal
4	3750 mg/kg	29 gm.	Lethal
5	3750 mg/kg	28 gm.	Lethal

The result showed that the mice survived the dose of 3750 mg/kg and died at a dose of 4100mg/kg. A confirmatory test was performed for confirming whether the result obtained was correct or not assuming the acute toxicity must be between 3750 mg/kg-4000mg/kg. The confirmatory test supported the results.

The toxicity of the plant depends upon the types of phytochemicals present in the plants. Flavonoids and tannins are non-toxic. Saponins can sometimes be toxic and it is used for killing fishes because saponin accumulates in the gills of the fishes hence, blocks the air passage. Cardiac glycosides are mainly used to boost up cardiac muscle but the slight increase in the dose may cause the instability of the cardiac muscle hence giving a heart attack (Kassop et al., 2013). Also, Kassop et al., (2013) concluded that cardiac glycosides are naturally occurring toxins and is a major clinical problem in parts of the developing world causing a significant number of deaths each year.

Furthermore, Ganpisetti et al., (2016) found cardiac glycoside commonly used in the treatment of chronic heart failure (CHF), atrial fibrillation, and reentrant supraventricular tachycardia. The lethal dose of most glycosides is approximately 5-10 times the minimal effective dose and only about twice the dose that leads to minor toxic manifestations (citations needed). Bhandary et al., (2012) found Glycosides as naturally cardio-active drugs used in the treatment of congestive heart failure and cardiac arrhythmia. Steroids are also toxic to some extent.

Conclusion

The study showed that saponin, steroids, flavonoids, cardiac glycosides and tannins were present in adequate amount in the leaves of *Lyonia ovalifolia*. The presence of steroids and cardiac glycosides were found to be toxic for the plant of *L. ovalifolia*. The leaves could be regarded as lethal as observed during laboratory analysis since the toxicity value is greater than 2000 mg/kg i.e. the LD_{50} was greater than 2000 mg/kg. Different authors of different literatures also support that the presence of cardiac glycosides to be toxic even if given in slightly higher doses. Hence, *L. ovalifolia* indicated that this plant could be potent rodenticides.

Acknowledgements

The authors would like to acknowledge, Ms. Jyoti Joshi, Deputy Director General Department of Plant Resources, Mr. Devi Prasad Bhandari, Chief of Natural Product Research Laboratory; Mr. Rajeshwor Ranjitkar and the entire family of National Products Research Laboratory (NPRL) and Department of Plant Resources (DPR) for their various help. Also the authors like to acknowledge Ms. Tshering Dolma Lama, Mr. Birendra Nepali, Mr. Suraj Risal, Mr. Manoj Acharya and the entire family of College of Applied Sciences-Nepal.

References

- Acharya, S., Shrestha, A., Gautam, B., Maharjan, S., Basyal , D., & Gyawali, R. (2014). Antioxidant and Antimicrobial Properties of Leaves of *Lyonia ovalifolia* (Wallich). *International Journal of Pharmaceutical & Biological Archives*; 2(4): 187-191

- Ahmed, T., Singh, S., & Pandey, S. (2013). Phytochemical Screening and Physicochemical Parameters of Crude Drugs: A Brief Review. *International Journal of Pharma Research & Review*; 2(12):53-60

- Bhandary, S., Suchetha, K., Bhat, V., Sharmila, K., & Bekal, M. (2012). Preliminary Phytochemical Screening of Various Extracts of Punica Granatum Peel, Whole Fruit and Seeds. *Nitte University Journal of Health Science*; 2(4)

- Fang, R., & Stevens, P. (2005). *Lyonia ovalifolia* (Wallich) Drude. Retrieved March 19, 2015, from Flora of China: http://www.efloras.org

- Ganpisetti, R., Chandluri, P., Dr. Lakshami, B., & Dr. Swami, A. (2016). Cardiac Glycosides Uses in Heart. *World Journal of Pharmaceutical and Medical Research*; 2(5)

- Joseph, B., Kumbhare, P., & Kale, M. (2013). Preliminary Phytochemical Screening of selected Medicinal Plants. *Int. Res. J. of Science & Engineering*; 1(2): 55-62

- Kassop, D., Donovan, M., Cohee, B., Mabe, D., Wedam, E., & Atwood, J. (2014). An unusual case of cardiac glycoside toxicity. *International Journal of Cardiology*; 170(3):434-7

- Kavishankar, G., Lakshmidevi, N., & Mahadeva Murthy, S. (2011). Phytochemical Analysis and Antimicrobial Properties of Selected Medicinal Plants against Bacteria associated with Diabetic Patients. *International Journal of Pharma and Bio Sciences*

- Manandhar, N. (2002). *Plants and People of Nepal.* Portland, Oregon, USA: Timber Press.

- Minj, E., Britto, S., Marandi, R., Kindo, I., & George, M. (2017). Phytochemical Analysis of Root and Bark of *Putranjiva roxburghii* Wall. (Euphorbiaceae). *Asian Journal of Pharmacology*; 9(7); 1035-1044

- Negi, R., Negi, Y., Uniyal, V., Saxena, S., & Bisht, S. (2012). Phytochemical Analysis and Antibacterial Activity of Three Indigenous Plants of Garhwal Himalaya against some Pathogenic Microorganisms. *Journal of Pharmacy Research*.

- Poongothai, A., Sreena, K., Sreejith, K., Uthiralingam, M., & Annapoorani, S. (2011). Preliminary Phytochemicals Screening of *Ficus racemosa* Linn. Bark. *International Journal of Pharma and Bio Sciences*; 2(2):431-434

- Ugochukwu, S., Uche, A., & Ifeanyi, O. (2013). Preliminary Phytochemical Screening of different Solvent Extracts of Stem Bark and Roots of *Dennetia tripetala* G. Baker. Pelagia Research Library. *Asian Journal of Plant Science and Research*; 3(3):10-13

- G.C.Y D, (2015). Biopesticides: Effective Alternatives to Organic Nepal. *Journal of Agriculture and Environment*; 16: 95-96

Wetland Flora of Jagadishpur Reservoir, Western Nepal

Prativa Budhathoki[1*], Chandra Kala Thakur[1], Madan Mohan Sandilya[2], Basu Dev Poudel[3]
[1]Plant Research Centre, Makawanpur,Nepal
[2]Forest Division Office, Kapilvastu, Nepal
[3]Environmental Services Nepal, Kathmandu, Nepal
*Corresponding email: *pratichhetry23@gmail.com*

Abstract

The Wetland flora of Jagdishpur Reservoir has been studied in the year 2021. This study was conducted to document the wetland flora found on foot trails around the Jagdishpur reservoir, Kapilvastu District. 70 species belonging to 67 genera of 37 families were recorded from the study area.13 species were invasive which seems that the wetland is under threat. Thus; this study provides baselineinformation about the wetland flora of the reservoir which might help in further research and in the conservation of wetland flora.

Keywords: *conservation, document, flora,invasive, baseline, wetland*

Introduction

Literature revealed that several works have been done in wetland flora of Nepal. Most of the works have been conducted in and around Kathmandu valley and in different regions.Flora of various lake and reservoir has been studied: Ghoda Ghodi Lake (Sha et al. 2002), Rara Lake (Basnet et al. 2012), Bet kot Lake (Basnet et al. 2016), RajaRani-Dhimal Pokhari (Chaudhary et al. 2017), Maipokhari (Bhattarai, K. R. 2018), Gajedi-Danapur Tal and Nanda Bhauju Tal (Dhakal et al. 2018).Besides that several other works in Algal flora and limnological studies (Chaudhary et al. 2018, Rai et al. 2019) have also been studied. According to Ghimire(2020) 711 wetland plant species under 382 genera in 112 families are enumerated in Nepal. Wetland flora of the Rupandehi district has been explored and nearly 115 species were recorded (Dhakal *et a.* 2019) but there is no documentation in the wetland flora of Jagdishpurreservoir. An extensive exploration is still needed to be carried out. Documentation of the flora of wetland species is essential for present and future research development. The present exploration has been conducted to find out the wetland flora of Jagadishpur reservoir. Thus, this study willprovide valuable baseline information regarding wetland flora of reservoir and will aid in further research and in conservation.

Materials and Methods

Study Area

Jagadishpur reservoir (27° 35' N and 83° 05' E) lies in Kapilvastu Municipality Ward 9 and 10, of Kapilvastu district of Nepal (Fig. 1), about 10 km north-west to the district headquarters Taulihawa. It has an elevation of 197 m with a tropical monsoon climate of hot rainy summer and cool, dry winter and coversan area of 225 hectares(Dhakal *et al*. 2015).

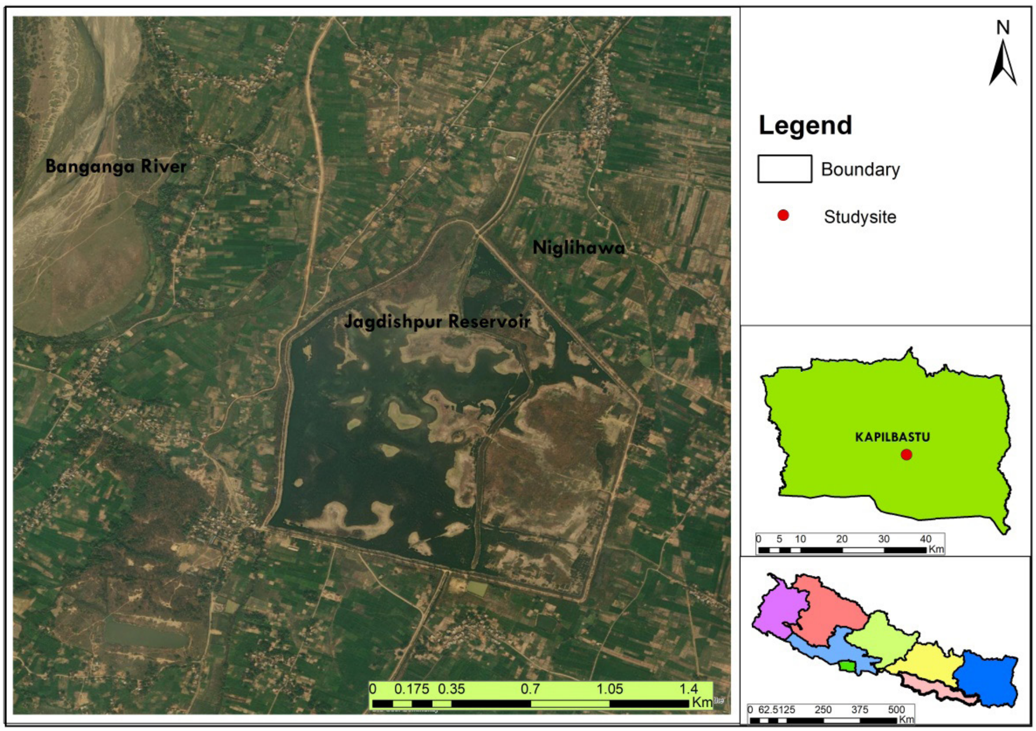


Figure – 1:Map of Study area

It was constructed in 1970s for irrigation purposes at the location of Jakhira Lake and is surrounded by agricultural land. The water was fed from Bangang River which has the catchment area in Churia hills.The reservoir is considered aparadise for birds. Several other aquatic plant species including other terrestrial species have been found in the reservoir and its adjoining areas.The Reservoir Management Committee involving the local community has taken its authority over its management. The reservoir has been utilized for the commercial fish culture and some of its southwest parts have been used for recreational (boating) purposes. Based on the criteria the Jagdishpur reservoir has been designated as Ramsar site in 2003 (Shiwakoti, 2009).

Method

This study was conducted in March, 2021. The survey was done during the beginning of the spring season which was carried out on foot. The survey followed a fixed route, starting from the main route and walking in a clockwise direction and ending at the starting point. Plant species were observed,photographed, recorded and collected for herbarium from the margin of the reservoir.Identification was done with the help of experts from the National Herbarium and plant laboratories (KATH), some other relevant literature(Fraser- Jenkins *et al.*2015, Ghimire et al. 2020),and annotated checklist of flowering plants (Press *et al.* 2000) and (The Plant list, 2013).

Results and Discussion

70 plant species belonging to 67 genera of 37 families were recorded. Out of 37 families Compositae (9 species) comprises the highest number of species followed by Leguminosae (7 species), Poaceae (4plant species), Malvaceae (4 species) and remaining families comprising less than 4 plant species (fig. 2). The study was focused only on macrophytes.

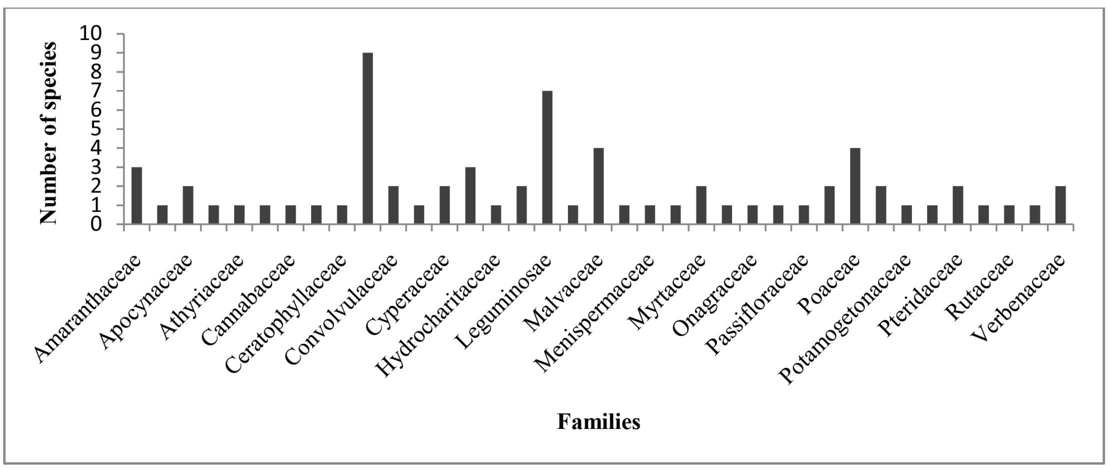


Figure – 2: Number of the plant species of Jagadishpur reservoir, Western Nepal

Most of the recorded plant species were under the plant groups of angiosperms and only a few were pteridophytes (3 species)and no gymnosperm was recorded from this place. Since this place was not appropriate for the plant belonging to gymnosperm. Plant species were divided into four life forms Herb, shrub, climber and tree. Herb (46 species) exhibits the highest number of plant species followed by shrub (11 species), tree (7 species) and climbers (6 species) (Annex 1).Submerged and free floating aquatic plant species *Hydrilla verticillata, Nymphoides hydrophylla, Nelumbo nucifera* were recorded respectively.Tree species like *Dalbergia sissoo*, *Syzgium cumini* (Jamun) were also recorded. Similarly, 13 invasive species *Ipomoea carnea*, *Xanthium strumarium, Ageratum houstonianum, Urena lobata, Parthenium hysterophorus (*Annex)were also recorded.Similar species have beenrecorded from the relevant literaturesfrom other wetlands (Basnet *et al.* 2016 and Chaudhary *et al.* 2018). Herbs exhibiting the highest concentration were similar with the result (Basnet *et al.* 2016, Paudel *et al*, 2016). In the present study 70 species were recorded that is more or less similar to the findings of Dhakal, *et al*. (2015) where they have recorded 68 species belonging to 35 families.

Conclusion

The present investigation in Jagdishpur reservoir documented 70plant species belonging to 67 genera of 37 families. Herbs (46 species) exhibits the highest number of plant species followe by shrub (11 species), tree (7 species) and climbers (6 species). Out of the 70 species 13 species were invasive which seems that the wetland is under threat. This study provides baseline information about the wetland flora of the reservoir. This study did not cover all the category of flora so, further exploration is recommended in this area at different seasons.

Acknowledgements

Authors are thankful to Plant Research Centre, Makawanpur and Division Forest Office, Kapilvastu for the coordination during the field work. We are grateful to National Herbarium and Plant Laboratories (KATH), Nepal for the plant identification.

References

- Basnet,R., Luitel, D. R., Bhattarai, K. & Joshi, M. D. (2016). Wetland flora of Betkot Lake, Far Western Nepal. *Journal of Natural History Museum*, **30**: 202- 208
- Bhattarai, K. R. (2018). Plants of Mai Pokhari Botanical Garden and Adjoining Areas, EastNepal. *Journal of Plant Resources*, **16**: 46- 56
- Chaudhary, R., & Niroula, B. (2017). Macrophytes of Rajarani-Dhimal Pokhari Wetland, Churia hills, Eastern Nepal. Nepalese. *Journal of Biosciences*, **7**(1): 77–82.
- Chaudhary, R. K. & Devkota, A. (2018).Evaluation of Limnological Status of Jagadishpur Reservoir, Kapilvastu District, Nepal. *International Journal of Applied Science Biotechnology*. **6** (3): 255 - 260
- Dhakal, G., Khanal, K., Baral, S., Basnyat, B., Poudyal, A., Shah, K., Malla, Y., Acharya, R., Khadka, S., Poudel, A., Joshi, R. &Sedai, R. (2015). *Biodiversity and Livelihood Assessments in Jagadishpur Reserviors Ramsar sites.* International Union for Conservation of Nature, Kathmandu, Nepal
- Dhakal, K. S., Saud, D. S. & Joshi, N. Wetland Flora of Rupandehi, District, Nepal. (2019), *Journal of Plant Resources.***17**: 58 – 68
- Fraser – Jenkins, C. F., Kandel, D. R. & Pariyar, S. (2015). *Fern and fern allies of Nepal*-1. Kathmandu, Nepal: Ministry of Forests and Soil Conservation, Department of Plant Resources, National Herbarium and Plant Laboratories.
- Ghimire, M. D., Dhakal, K. S., & Saud, D. S. (2020). A checklist of wetland flora reported from Nepal. *Department of plant resources Kathmandu, Nepal*.
- Paudel, H. R. & Pandey, T. R. (2016). Documentation of the Flora of Ramaroshan Wetland Complex Achham, West Nepal, *Journal of Plant Resources*. **38**: 16 -21
- Press, J. R.., Shrestha, K. K. & Sutton., D.A. (2000). *Annotated checklist of the flowering plants of Nepal*. London: The Natural history Museum.
- Sah, J. P., Singh, R. L. & Bhatta, N. (2002). Floristic Diversity and Use of Plants in GhodaGhodi Lake Area, Nepal, *Journal of Natural History Museum*. **21**: 243 – 266
- Shiwakoti, M. & Karki, J. B. (2009). Conservation status of Ramsar sites of Nepal Tarai: an overview. *Botanica orientalis*, **6**: 76 – 84
- The Plant List .(2013). Version 1.1 Published on the Internet; http://www.theplantlist.org/ (accessed on 8th September)

Annex

S.N.	Scientific Name	Family	Life form
1	*Alternanthera paronychioides* A.St.-Hil.	Amaranthaceae	Herb
2	*Achyranthes aspera* L.	Amaranthaceae	Herb
3	*Alternanthera sessilis* (L.) R.Br. ex DC.	Amaranthaceae	Herb
4	*Centella asiatica* (L.) Urb.	Apiaceae	Herb
5	*Ichnocarpus frutescens* (L.) W.T.Aiton	Apocynaceae	Climber/ lianas
6	*Calotropis procera* (Aiton) Dryand.	Apocynaceae	Shrub
7	*Colocasia esculenta* (L.) Schott	Araceae	Herb
8	*Diplazium esculentum* (Retz.) Sw.	Athyriaceae	Herb
9	*Euploca strigosa (Willd.)* Diane & Hilger	Boraginaceae	Herb
10	*Cannabis sativa* L.	Cannabaceae	Herb
11	*Cerastium arvense* L.	Caryophyllaceae	Herb
12	*Ceratophyllum demersum* L.	Ceratophyllaceae	Herb
13	*Cyanthillium cinereum* (L.) H.Rob.	Compositae	Herb
14	*Xanthium strumarium* L.	Compositae	Herb
15	*Ageratum houstonianum* Mill.	Compositae	Herb
16	*Parthenium hysterophorus* L.	Compositae	Herb
17	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Compositae	Herb
18	*Tridax procumbens* (L.) L.	Compositae	Herb
19	*Cirsium*	Compositae	Herb
20	*Hypochaeris radicata* L.	Compositae	Herb
21	*Ageratum conyzoides* (L.) L.	Compositae	Herb
22	*Ipomoea carnea* Jacq.	Convolvulaceae	Shrub
23	*Ipomoea aquatica* Forssk.	Convolvulaceae	Trailing vine
24	*Coccinia grandis* (L.) Voigt	Cucurbitaceae	Climber
25	*Cyperus* sp.	Cyperaceae	Herb
26	*Eleocharis atropurpurea* (Retz.) J.Presl & C.Presl	Cyperaceae	Herb
27	*Chrozophora rottleri* (Geiseler) A.Juss. ex Spreng.	Euphorbiaceae	Herb

S.N.	Scientific Name	Family	Life form
28	*Croton bonplandianus* Baill.	Euphorbiaceae	Herb
29	*Euphorbia hirta* L.	Euphorbiaceae	Herb
30	*Hydrilla verticillata* (L.f.) Royle	Hydrocharitaceae	Herb
31	*Hyptis suaveolens* (L.) Poit.	Lamiaceae	Herb
32	*Clerodendrum infortunatum* L.	Lamiaceae	Shrub
33	*Lathyrus sativus* L.	Leguminosae	Climber
34	*Alysicarpus vaginalis* (L.) DC.	Leguminosae	Herb
35	*Trifolium pratense* L.	Leguminosae	Herb
36	*Senna occidentalis* (L.) Link	Leguminosae	Shrub
37	*Dalbergia sissoo* DC.	Leguminosae	Tree
38	*Leucaena leucocephala* (Lam.) de Wit	Leguminosae	Tree
39	*Acacia nilotica* (L.) Delile	Leguminosae	Tree
40	*Utricularia aurea* Lour.	Lentibulariaceae	Herb
41	*Sida acuta* Burm.f.	Malvaceae	Shrub
42	*Sida rhombifolia* L.	Malvaceae	Shrub
43	*Sida cordata* (Burm.f.) Borss.Waalk.	Malvaceae	Shrub
44	*Urena lobata* L.	Malvaceae	Shrub
45	Melia azedarach *L.*	Meliaceae	Tree
46	*Cissampelos* sp.	Menispermaceae	Climber
47	*Nymphoides hydrophylla* (Lour.) Kuntze	Menyanthaceae	Herb
48	*Syzygium cumini* (L.) Skeels	Mrytaceae	Tree
49	*Psidium guajava* L.	Myrtaceae	Tree
50	*Nelumbo nucifera* Gaertn.	Nelumbonaceae	Herb
51	*Ludwigia*	Onagraceae	Herb
52	*Oxalis corniculata* L.	Oxalidaceae	Herb
53	*Passiflora foetida* L.	Passifloraceae	Climber
54	*Phyllanthus niruri* L.	Phyllanthaceae	Herb
55	*Phyllanthus reticulatus* Poir.	Phyllanthaceae	Shrub
56	*Cynodon dactylon* (L.) Pers.	Poaceae	Herb

S.N.	Scientific Name	Family	Life form
57	*Paspalum distichum L.*	Poaceae	Herb
58	*Phragmites karka (Retz.) Trin. ex Steud.*	Poaceae	Herb
59	*Polypogon fugax* Nees ex Steud.	Poaceae	Herb
60	*Persicaria hydropiper* (L.) Delarbre	Polygonaceae	Herb
61	*Rumex nepalensis* Spreng.	Polygonaceae	Herb
62	*Potamogeton nodosus* Poir.	Potamogetonaceae	Herb
63	*Anagallis arvensis* L.	Primulaceae	Herb
64	*Adiantum philippense* L.	Pteridaceae	Herb
65	*Pteris vittata* L.	Pteridaceae	Herb
66	*Ziziphus*sp	Rhamnaceae	Shrub
67	*Murraya paniculata* (L.) Jack	Rutaceae	Shrub
68	*Physalis* sp.	Solanaceae	Herb
69	*Phyla nodiflora* (L.) Greene	Verbenaceae	Herb
70	*Gmelina arborea* Roxb.	Verbenaceae	Tree