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).

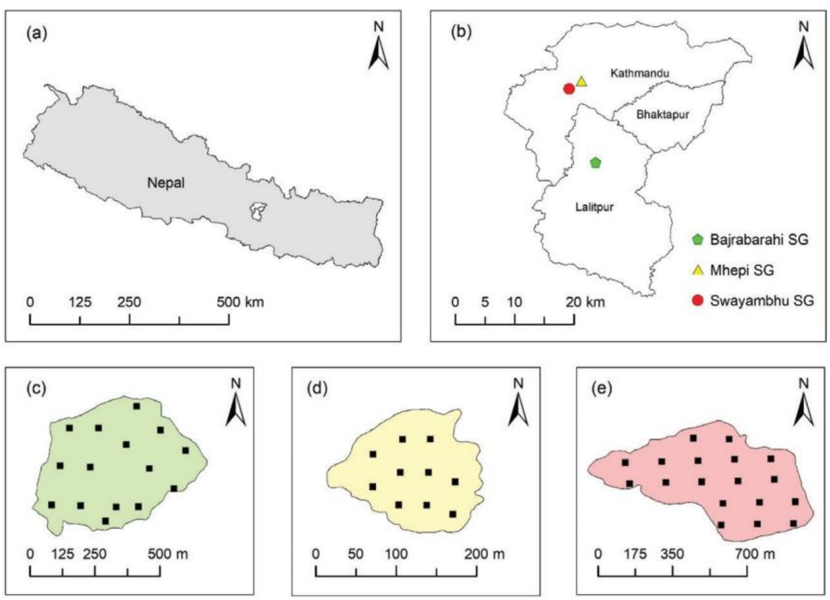

Figure 1.Study area map: (a) location of the Kathmandu Valley in Nepal, (b) location of the studied SGs in the Kathmandu Valley, (c) sampling points in Bajrabarahi SG, (d) sampling points in Mhepi SG, and (e) sampling points in Swayambhu SG.

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).

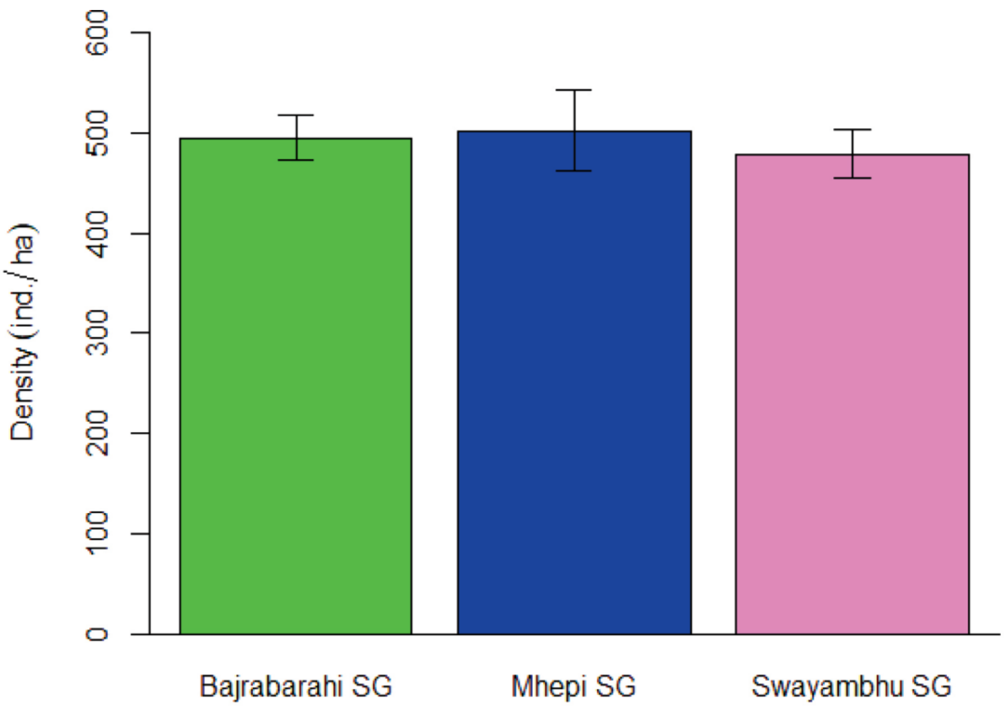

Figure 2. Meanwoody species density in the studied forests.

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 ($p = 0.156$).

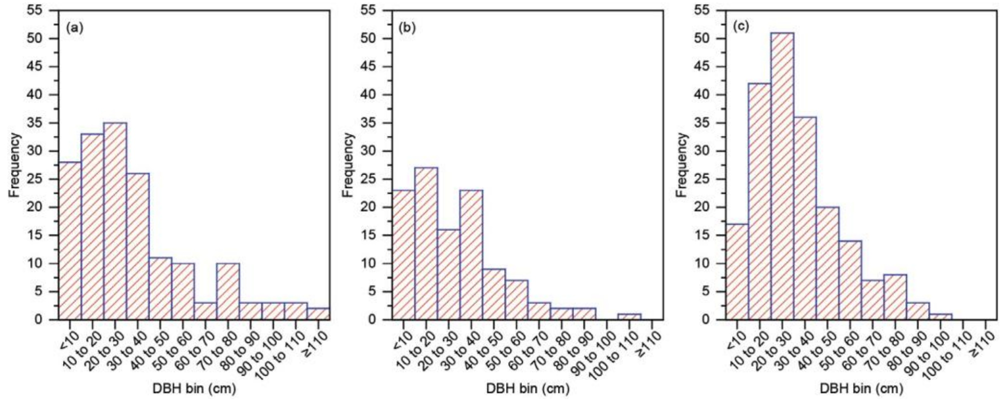

Figure 3. DBH distribution of woody species in (a) Bajrabarahi SG, (b) Mhepi SG, and (c) Swayambhu SG.

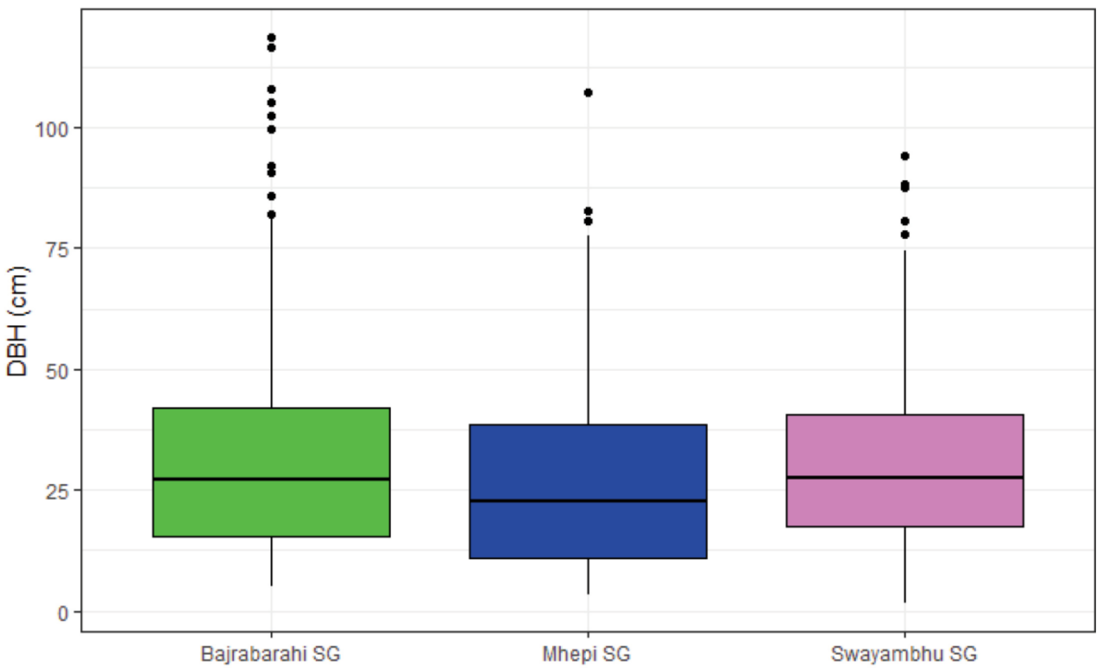

Figure 4.DBH distribution of woody species in the studied forests.

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).

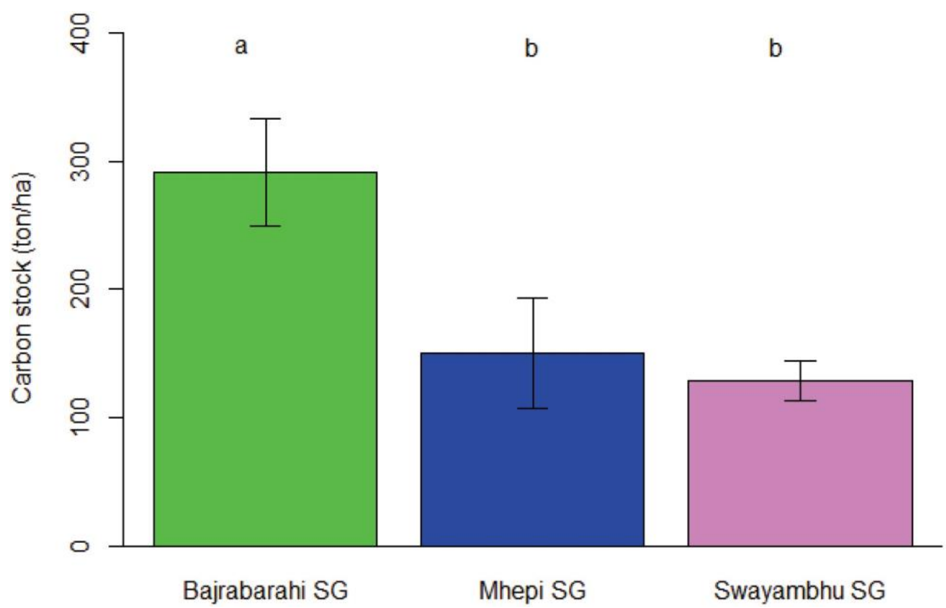

Figure 5. Meancarbon stock in the studied forests; the similar and different lower-case letters on the top of the bars represent,respectively, the non-difference and statistical difference (α = 5%) in mean carbon stock between the studied SGs.

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.