Journal of Pure and Applied Agriculture (2019) 4(1): 21-28
ISSN (Print) 2617-8672, ISSN (Online) 2617-8680
http://jpaa.aiou.edu.pk/

RESEARCH PAPER

Variation in tree biomass and carbon stocks with respect to altitudinal gradient in the Himalayan forests of Northern Pakistan

Abdul Mannan[1, 2*], Feng Zhongke[1, 3*], Tauheed Ullah Khan[4], Muhammad Asif Khan[5] and Muhammad Tariq Badshah[5]

[1]Beijing Key Laboratory of Precision Forestry, Beijing Forestry University, 100083 Beijing, China
[2]Forest, Wildlife and Fisheries Department, Governmentt of Punjab, Lahore 54500, Pakistan
[3]Mapping and 3S Technology Center, Beijing Forestry University, Beijing 100083, China
[4]School of Nature Conservation, Beijing Forestry University, Beijing 100083, China
[5]School of Forestry, Beijing Forestry University, 100083 Beijing, China

*Corresponding author: Feng Zhongke (fengzhongke@126.com)

Key Message: This study shows the importance and effects of altitude on the stored tree biomass, carbon, basal area and density in the Himalayan forests of Pakistan.

ABSTRACT: Forest ecosystems play a significant role in biomass, carbon stocks and the global carbon cycle. They show variation along with the elevation gradient. This study was conducted to evaluate the variation in tree biomass and carbon stocks with respect to the elevation in the Himalayan forests of Northern Pakistan. The study area was categorized into four elevation classes namely ELV-1 (500 m – 1000 m), ELV-2 (1000 m – 1500 m), ELV-3 (1500 m – 2000 m), ELV-4 (2000 m – 2500 m). Our results showed that the stem density at ELV-1 was found to be the highest such as 761.18 trees ha^{-1} than that of 423.82 trees ha^{-1} at ELV-2, 428.82 trees ha^{-1} at ELV-3 and 457.82 trees ha^{-1}at ELV-4, respectively. However, the biomass and stored carbon contents were found to be the highest at ELV-4 such as 474.08 Mg ha^{-1} and 279.89 Mg C ha^{-1}, respectively as compared to ELV-3, ELV-2 and ELV-1 (lower elevations). Similarly, the basal area (BA) was recorded to be the highest at ELV-4 such as 76.41 m^2 ha^{-1}, while at ELV-1 it was found to be the lowest with 13.1 m^2 ha^{-1}. A decreasing trend was noticed in the density of the study area with an increase in altitude. The results highlighted the variation in density, BA, stem volume, tree biomass and tree carbon with respect to elevations. This study will provide scientific information to researchers about the role of altitude in the studied parameters, which will help the foresters in formulating the forest management policies.

Keywords: Altitude, Forest biomass, Carbon, Himalayan forests

How to cite this article:

Mannan, A., Zhongke, F., Khan, T. U., Khan, M. A., & Badshah, M. T. (2019). Variation in tree biomass and carbon stocks with respect to altitudinal gradient in the Himalayan forests of Northern Pakistan. *Journal of Pure and Applied Agriculture*, *4*(1), 21-28.

INTRODUCTION

The altitude plays an important role in determining the forest type controlling the environmental factors and geographical variation (Sun et al., 2013). The variation in altitude directly influences the temperature, humidity, light intensity and rainfall that cause a change in the type of forest (Chen et al., 2014). The altitude gradient also has a great effect on the ecological distribution of forest type in mountainous regions (Wei et al., 2015). According to the Inter-Governmental Panel on Climate Change (IPCC), the forest ecosystems cover 30% area of the world which are the largest sink storing carbon worldwide (Inter-Governmental Panel on Climate Change [IPCC], 2006). They also play an important role in balancing terrestrial carbon cycle globally (Dong et al., 2003). The soil contains 33% of the total carbon in the world (Food and Agriculture Organization [FAO], 2010a), while 77% carbon is stored in the plants (IPCC, 2001). Forested land has 30-50 times more carbon storing potential than that of barren lands (Houghton & Joseph, 1995). Carbon flux is addressed by the United Nations Framework Convention on Climate Change (UNFCCC), and since 1990, the (IPCC) focused on the role of forest in maintaining carbon cycle globally (IPCC, 2006). Human disturbance and natural causes affect the structure, composition, and yield and carbon dynamics of a forest ecosystem (Zheng et al., 2011). Natural disasters and human needs should be monitored and quantified accurately over a large scale to enhance the forest conservation, management and productivity (Zheng et al., 2011).

The first comprehensive assessment of land cover in Pakistan was done using remote sensing in 1992 by the Food and Agriculture Organization (FAO, 2010b). The report showed that the total forest area of Pakistan is composed of about 3.5 million ha, making just 4.1% of its total area (Government of Pakistan [GOP], 1992). A decrease in forest cover was observed especially in the mountainous region of the country by the International Union for the Conservation of Nature (IUCN, 2002). It is also reported that the forest area in Pakistan has been decreased within the range of 3.1%-3.6% (FAO, 2003), while a World Bank report showed that the total forest cover area of Pakistan has declined by about 1.9% of its total area (World Bank, 2015). Only a few countries in the world have reliable land use change (LUC) and land degradation (LD) data over the period of time (FAO, 2010b). This hinders the effective forest management policies, and the quantitative assessment of the LD and LUC. In Pakistan LD and LUC are linked to natural and human-induced factors like wind, insect, forest fire, flood, LUC, forest felling and encroachment etc. (Mannan et al., 2018).

Different forest types have different carbon storing potentials due to variation in biomass (Smith & Heath, 2004). There are nine major forest types in Pakistan (FAO, 2010a). Variation in forest type in the country is mainly due to the altitudinal gradient, mean annual rainfall and temperature (World Wide Fund [WWF], 2009). The variation in altitude directly affects the biomass carbon potential of the forest (Chen et al., 2014). The variation in species distribution, biodiversity, and soil composition is also documented across different types of forest (Sharma, 2009). The subtropical and moist temperate forests found in northern parts of Pakistan are not only rich in floral and faunal diversity but also are acknowledged as the major carbon sink as compared to the other forest types (Ahmad et al., 2018). In subtropical forests of Pakistan, the forest types at different altitudes affect the forest biomass and carbon contents as this region has a vital role in the sequestering of carbon (Nizami, 2012). The effect of altitude on the stem density, basal area, biomass, and carbon has not been studied before in Himalayan forests of Northern Pakistan. Therefore, this study was aimed to provide the detail quantification of stem density, basal area, biomass and carbon contents in the forest of the study area at different altitudes.

MATERIALS AND METHODS

Study area

The study was conducted in the Himalayas forests at Margallah Hills National Park (MHNP) and Murree Forest Division (MFD) (33°49'33.22"N and 73°21'59.87"E) of northern Pakistan within the elevation range of 522 m – 2267 m (Fig. 1). The total area under study was 621.74 km^2. The area receives a mean annual rainfall of about 80 mm, while the mean annual minimum temperature is 3 °C and the maximum temperature is 45 °C (Pakistan Meteorological Department [PMD], 2017). The study area has diverse flora and fauna. The major tree species reported from the area are *Abies spp, Acacia modesta, Pinus roxburghii, Cedrus deodara*, *Ziziphus spp, Pinus wallichiana*, *Olea ferruginea, Picea smithiana, Quercus incana*, *Dodonea viscose* and *Aesculus indica* (Shahzad et al. 2015), while the wildlife species included common leopard *(Panthera pardus)*, rhesus monkey *(Macaca mulatta)*, jackal (*Canis aureus*), porcupine (*Hystrix indica)*, barking deer (*Muntiacus muntjak)*, foxes and wild boars (*Sus scrofa)*. The area also hosts a rich diversity of bird species including cheer pheasant (*Catreus wallichii*), *brown partridge (Alectoris chukar)* and several genera of reptiles (WWF, 2009).

Research design

The study was carried out in three main forests namely subtropical broad-leaved forest, chir pine forest, and moist temperate forest. The study area was divided into four levels on the basis of altitude such as 500 m – 1000 m (ELV-1), 1000 m – 1500 m (ELV-2), 1500 m – 2000 m (ELV-3) and 2000 m – 2500 m (ELV-4). A total of 20 sample plots (20 m × 30 m) were taken in each altitudinal level (ELV-1, ELV-2, ELV-3, ELV-4) that covered all the major habitats and tree species of the study area. The sample plots were taken randomly, first the sample plot was measured using metallic measuring tape and after that the plot boundary was marked with wooden pegs (30 cm × 5 cm × 5 cm) and rope. The trees present in the sample plot were marked with white paint. The diameter at breast height (DBH > 5 cm) of all trees in the sample plot was measured using diameter tape and the height of the trees was measured using Abney's Level.

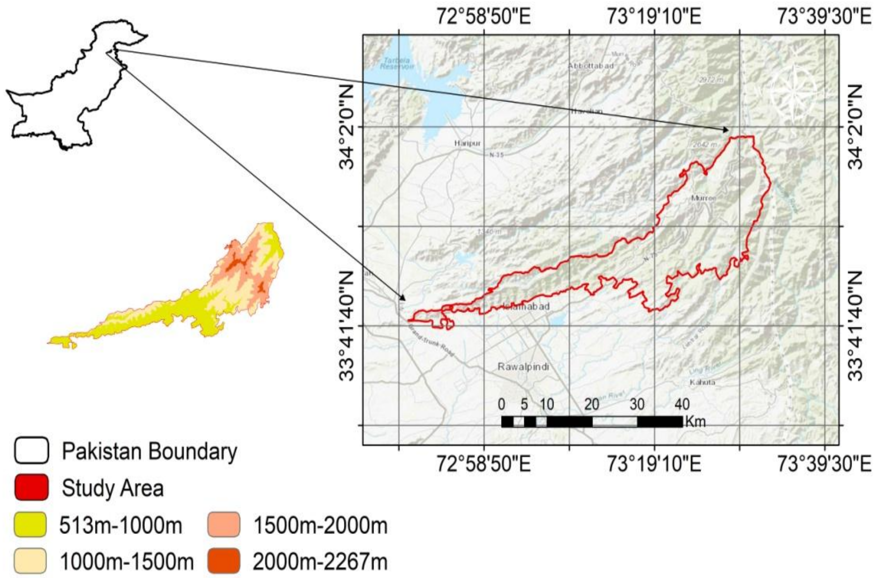

Fig. 1 Study area of Himalayan forest of Pakistan

Biomass and carbon assessment

All the trees in the plot were categorized into different diameter classes from 6 cm to 45 cm. Tree volume (V) of all the species was measured using equation 1 (Newbery, 2009):

$$V = \frac{\pi}{4} \times d^2 \times h \times f.f \quad ..... (1)$$

Where d^2 is the square of tree diameter, *h* is the height of the tree and *f.f* is the form factor which is the tapering of a tree. The specific *f.f* value was obtained from the previous research and literature (Haripriya, 2002).

The biomass of stem (BM_S) was determined by multiplying the V with Basic Wood Density (BWD) (Haripriya, 2002). The BWD of each species was obtained from the available literature (Sheikh, 1993; Haripriya, 2002) as shown in equation 2:

$$BM_s = V \times BWD \quad ..... (2)$$

The total tree biomass (BM_{TT}) was obtained by multiplying the stem biomass (BM_S) with biomass expansion factor (BEF), where BEF value 1.51 was used in previous research for Himalayan forests (Haripriya, 2002; IPCC, 2006). The total biomass (BM_{TT}) for each species was determined by using equation 3:

$$\mathrm{BM_{TT}} = BM_S \times BEF \quad ..... (3)$$

After determining the BM_{TT} for each species, the biomass of forest ecosystem (BM_E) was calculated by adding the biomass of all species present in the plot. To obtain the carbon content (CC) from the BM_E, we used conversion factor 0.5 which is widely used throughout the world by IPCC (IPCC, 2006), and previous researches (Brown & Lugo, 1982; Saugier et al., 2001) for subtropical and moist temperate forest of sub-continent using equation (4):

$$CC = BM_E \times 0.5 \quad ..... (4)$$

Statistical analysis

The data was analyzed by one-way analysis of variance (ANOVA) at $p<0.05$. The Randomized Block Design (RCBD) was used to find out the significant difference in forest inventory results along altitudes gradients (altitudinal levels) by using the software, Statistix v. 8.1 (Analytical Software, 2005).

RESULTS AND DISCUSSION

Density of tress

The results from forest inventory showed that the density of forest at ELV-1 was 761.18 trees ha^{-1} which was significantly ($p \leq 0.05$) higher than that of the density of forest at ELV-4 (457.82 trees ha^{-1}), ELV-3 (428.82 trees ha^{-1}) and ELV-2 (423.82 trees ha^{-1}), respectively (Fig. 2). The forest at ELV-1 is dense because of subtropical broadleaved evergreen forest type (Mannan et al., 2018). This forest type supports tree species like *Olea ferruginea, Acacia modesta, Quercus incana, Ziziphus spp, Dodonea viscosa* (Sun et al., 2013; Mannan et al., 2018). These plants grow well in association with each other making the forest dense (Saeed et al., 2016), while this forest has low biomass due to absence of tall trees. The previous studies showed the density of 400-1600 trees ha^{-1} (Singh et al., 1994), 594 trees ha^{-1} (Haripriya, 2002; Nizami, 2012) for this type of forest. The ELV-2 and ELV-3 mostly have subtropical chir pine forest which is dominated by *Pinus roxburghii* (Amir et al., 2018). Our results also showed that the densities at ELV-2, ELV-3 and ELV-4 showed non-significant relation with each other (Fig. 2). Furthermore, ELV-1 provides the best growing platform to the drought tolerant species like *Acacia modesta*, *Olea ferruginea* and *Celtiserio carpa* adding to its high density.

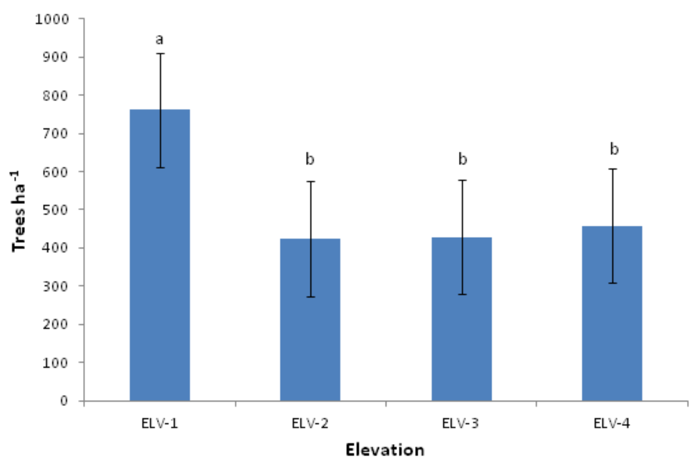

Fig. 2 Density of trees ha^{-1} with elevation

Basal area

The basal area (BA) calculated at ELV-4 was 76.41 m^2 ha^{-1}, which was significantly ($p \leq 0.05$) higher than the results of BA at ELV-2, ELV-3 and ELV-1 i.e. 32.57, 30.31 and 13.1 m^2 ha^{-1}, respectively (Fig. 3). The ELV-4 has the moist temperate forests that have tall mature forest trees usually having the characteristic of natural regeneration. Moreover, these trees have larger diameter than that of subtropical chir pine forest and subtropical broad-leaved forest. Therefore, they have large basal area (FAO, 2010a). Similarly, results of stem biomass were recorded as 300.1 Mg ha^{-1} at ELV-4, 138.5 Mg ha^{-1} at ELV-3, 136.3 Mg ha^{-1} at ELV-2 and 59.73 Mg ha^{-1} at ELV-1 (Fig. 4). This may be due to the fact that ELV-4 has the moist temperate forest having tall mature coniferous trees i.e. *Abies spp*, *Cedrus deodara*, *Pinus wallichiana*, *Picea smithiana*, *Taxus wallichiana* as well as the fast growing broad leaved species like *Quercus incana*, *Aesculus indica*, *Populus spp* and *Rubinia pseudoacatia* (Shahzad et al., 2015). Previous studies showed that the old mature forest has more basal area due to more secondary growth (Saranya et al., 2016). Some species like *Abies pindrow* and *Picea smithiana* can reach up to 120 feet in height, thus this forest type has high stem biomass. Furthermore, this forest supports shrubby vegetation as well as a great diversity of herbs (Shahzad et al., 2015; Amir et al., 2018). This forest type consists of almost 150 species of herbs, 45 kinds of weeds and 27 climbing species (Ali et al., 2007). While at ELV-2 and ELV-3, mostly subtropical chir pine forests are present with some associated broad-leaved species having small diameters (Singh et al., 1994; Nizami, 2012). However, at ELV-1, all broad-leaved evergreen species are present, having stunted growth, some having bushy and shrubby appearance i.e. *Olea ferruginea*, *Ziziphus spp*, *Dodonea viscose*, *Quercus spp* etc. Due to this reason, they have high density with low BA and stem biomass (Ahmad & Nizami, 2015).

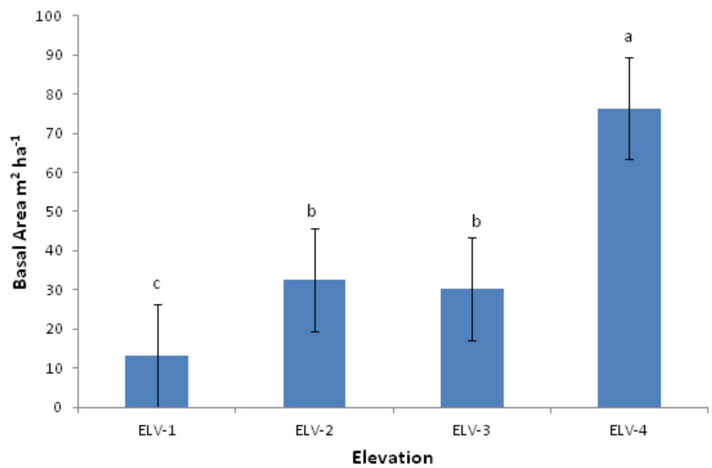

Fig. 3 Variation in basal area ha^{-1} with elevation

Change in biomass

ELV-4 showed biomass (474.08 Mg ha^{-1}) and carbon (279.89 Mg C ha^{-1}) which was higher and significantly ($p \leq 0.05$) different than that of the biomass at ELV-3 (212.91 Mg ha^{-1}), ELV-2 (210.45 Mg ha^{-1}) and ELV-1 (70.80 Mg ha^{-1}), respectively. The carbon contents recorded at ELV-3, ELV-2 and ELV-1 were 156.01 Mg C ha^{-1}, 157.46 Mg C ha^{-1} and 76.53 Mg C ha^{-1}, respectively. The presence of moist temperate forest at ELV-4 supports tall trees like *Abies spp*, *Cedrus deodara*, *Pinus wallichiana* and *Picea smithiana.* These trees are usually tall having height ranging from 50-120 ft. The other supporting feature for high biomass and carbon contents is the presence of more understory vegetation which is greater at ELV-4 as compared to ELV-3, ELV-2 and ELV-1 (Tahir et al., 2013).

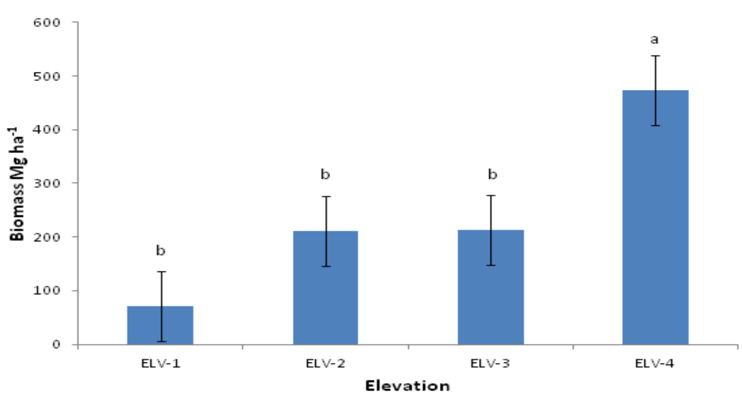

Fig. 4 Change in biomass (Mg ha^{-1}) with elevation

Change in carbon contents

The climatic conditions at ELV-4 also support high vegetative growth as this area receives a relatively high annual rainfall (1000 mm – 1800 mm) mostly in the summer season (PMD, 2015). Moreover, the forest at ELV-4 is less prone to forest fire as compared to ELV-3, ELV-2 and ELV-1 (Nafees & Asghar, 2009). On the other hand, the ELV-2 and ELV-3 have pure *Pinus roxburghii* forest in which forest fire occurs regularly in summer due to the falling of dry needles making the floor of the forest prone to combustion (Nizami, 2012). These forest fires also cause the reduction of biomass and carbon stocks. The tree carbon results were higher at ELV-4 (279.89 Mg C ha^{-1}), while 156.01 Mg C ha^{-1}, 157.46 Mg C ha^{-1} and 76.53 Mg C ha^{-1} were recorded at ELV-3, ELV-2 and ELV-1, respectively (Fig. 5). Furthermore, tall conifers like *Abies pindrow*, *Texus bacatta*, *Picea smithian* and *Thuja orientalis* attain the height up to 150 feet (Ahmad & Nizami, 2015). The other reason is that the forest at ELV-4 is mostly included in mature trees with natural regeneration. The mature trees with secondary growth have more whorls of branches and potential to store carbon contents (Singh et al., 1994).

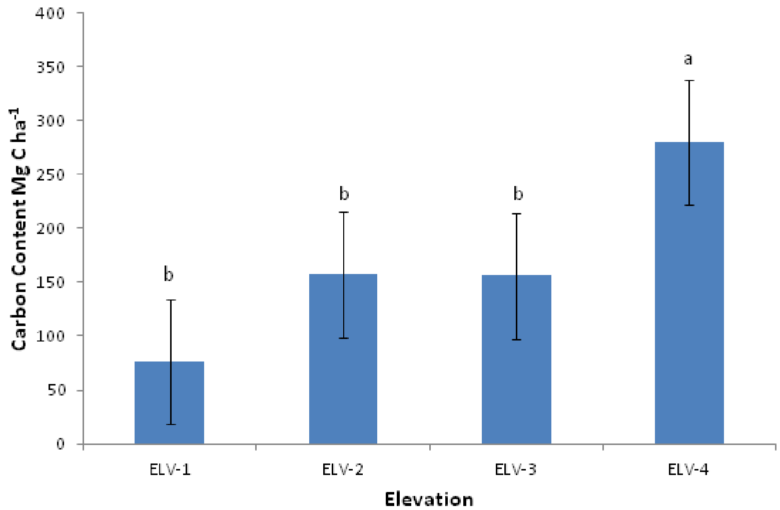

Fig. 5 Change in carbon contents (Mg C ha^{-1}) with elevation

CONCLUSION

The elevation plays an important role in the forest ecosystem, forest biomass, forest carbon, density and basal area. Our results showed that the basal area, biomass, and carbon contents increase with the increasing elevation, while the stem density (number of trees ha^{-1}) decreases with the increasing elevation. The moist temperate forest at high altitudes has more potential of storing biomass and carbon as compared to chir pine forest and subtropical broad-leaved at low altitude. The forest at higher altitudes is mostly moist temperate forest and stores more biomass and carbon as compared to the forest at lower elevations, chir pine forest and subtropical broadleaved forest. This study will help the forest manager as a guide line for making forest conservation and management policies.

Author Contribution Statement: Abdul Mannan collected the field data and wrote the manuscript. Feng Zhongke supervised the research study. Tauheed Ullah Khan analyzed the data. Muhammad Asif Khan helped in data collection. Muhammad Tariq Badshah edited and formatted the manuscript.

Conflict of Interest: The authors certify that they have no conflict of interest to declare in the subject matter or materials discussed in this manuscript.

Acknowledgements: This research was supported by the National Science Foundation of China (No. U1710123), the Natural Science Foundation of Beijing (Key Program, No.6161001), and "Precision Forestry Key Technology and Equipment Research" of medium long-term project of Beijing Forestry University (No. 2015ZCQ-LX-01).

REFERENCES

Ahmad, A., & Nizami, S. M. (2015). Carbon stocks of different land uses in the Kumrat valley, Hindu Kush region of Pakistan. *Journal of Forest Research*, *26*, 57-64.

Ahmad, A., Liu, Q. I. J., Nizami, S. M., Mannan, A., & Saeed, S. (2018). Carbon emission from deforestation, forest degradation and wood harvest in the temperate region of Hindukush Himalaya, Pakistan between 1994 and 2016. *Land Use Policy*, *78*, 781-790.

Ali, T., Ahmad, M., Shahbaz, B., & Suleri, A. (2007). Impact of participatory forest management on vulnerability and livelihood assets of forest-dependent communities in Northern Pakistan. *International Journal of Sustainable Development & World Ecology*, *14*(2), 211-223.

Amir, M., Liu, X., Ahmad, A., Saeed, S., Mannan, A., & Muneer, M. A. (2018). Patterns of biomass and carbon allocation across chronosequence of chir pine (*Pinus roxburghii*) forest in Pakistan: Inventory-based estimate. *Advances in Meteorology, 2018,* 8. doi: 10.1155/2018/3095891

Analytical Software. 2005. Statistix version 8.1: User's manual. Analytical Software, Tallahassee, Florida.
Brown, S., & Lugo, A. E. (1982). The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica*, *14*(3), 161-187.
Chen, Y., Yang, X., Yang, Q., Li, D., Long, W., & Luo, W. (2014). Factors affecting the distribution pattern of wild plants with extremely small populations in Hainan island, China. *Plos One*, *9*, 97751.
Dong, J., Robert, K., Myneni, R., Compton, T., Kauppi, P., Liski, J., Buermann, W., Alexeyev, V., & Hughes, M. (2003). Remote sensing estimates of boreal and temperate forest woody biomass : Carbon pools, sources, and sinks. *Remote Sensing of Environment*, *84*(3), 393-410.
Food and Agriculture Organization [FAO]. (2003). *State of world's forests.* Food & Agriculture Organization Rome. Retrieved from http://www.fao.org/docrep/005/Y7581E/Y7581E00.HTM.
FAO. (2010a). *Global forest resources assessment.* Food and Agriculture Organization of the United Nations. Rome, Italy. Retrieved from http://www.fao.org/forestry/fra/fra2010/en/
FAO. (2010b). Pakistan forestry outlook study Islamabad, Pakistan. Retrieved from www.fao.org/docrep/014/am623e/am623e00.pdf
Government of Pakistan [GOP]. (1992). *Government of Pakistan. Forestry sector master plan: Ministry of Food and Agriculture*. Islamabad, Pakistan. Retrieved from www.fao.org/docrep/014/am623e/am623e00.
Haripriya, G. S. (2002). Biomass carbon of truncated diameter classes in Indian forests. *Forest Ecology and Management*, *168*(1), 1-13.
Houghton, R., & Joseph, L. (1995). Continental scale estimate of the biotic carbon flux from land cover change 1850 – 1990. ORNL/CDIAC-79, NDP-050, Carbon Dioxide Information Analysis Center, Oak
Inter-Governmental Panel on Climate Change [IPCC]. (2006). *Guidelines for national greenhouse gas inventories*. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/
IPCC. (2001). *Climate change 2001: The scientific basis*. In J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell & C. A. Johnson (Eds). Cambridge, UK: Cambridge University Press.
International Union for the Conservation of Nature [IUCN]. (2002). *The world conservation union. Environmental issues*. Retrieved from https://www.iucn.org/downloads/cec_history_annex_28sept08.pdf
Mannan, A., Zhongke, F., Ahmad, A., Liu, J., Saeed, S., & Mukete, B. (2018). Carbon dynamic shifts with land use change in Margallah Hills National Park, Islamabad (Pakistan) from 1990 to 2017. *Applied Ecology and Environmental Research*, *16*(3), 3197-3214.
Nafees, M., & Asghar, A. (2009). Forest fire events in Swat valley, Pakistan. *Pakistan Journal of Plant Sciences*, *15*, 31-37.
Newbery, D. M. (2009). M. S. Philip Measuring trees and forests. (2nd Ed.) 1994. xiv + 310 pp. ISBN 0-85198-883-0 (pbk). CAB International, Wallingford, Oxon. Price: £24.50/US $46.50. *Journal of Tropical Ecology*, *11*(2), https://doi.org/10.1017/S0266467400008658
Nizami, S. M. (2012). The inventory of the carbon stocks in sub-tropical forests of Pakistan for reporting under Kyoto protocol. *Journal of Forestry Research 23*(3), 377-384.
Pakistan Meteorological Department [PMD]. (2015). *Rainfall statistics of Islamanad*. Retrieved from http://www.pmd.gov.pk/FFD/index_files/daily/rainfall_data.htm
PMD. (2017). *Climate change statistics of Pakistan.* Retrieved from www.pmd.gov.pk/report_rnd.pdf
Saeed, S., Ashraf, M. I., Ahmad, A., & Rahman, Z. (2016). The bela forest ecosystem of district Jhelum, a potential carbon sink. *Pakistan Journal of Botany*, *48*, 121-129.
Saranya, L., Reddy, S., & Rao, P. (2016). Estimating carbon emissions from forest fires over a decade in Similipal Biosphere Reserve, India. *Remote Sensing Applications: Society and Environment*, *4*, 61-67.
Saugier, B., Roy, J., & Mooney, H. A. (2001). Estimations of global terrestrial productivity: Converging toward a single number. *Terrestrial Global Productivity* (pp. 543-557). San Diego: Academic Press.
Shahzad, N., Saeed, U., Gilani, H., Ahmad, S. R., Ashraf, I., & Irteza, S. M. (2015). Evaluation of state and community/private forests in Punjab, Pakistan using geospatial data and related techniques. *Forest Ecosystems*, *2*(1), 7. doi: 10.1186/s40663-015-0032-9
Sharma, D. P. (2009). Biomass distribution in sub-tropical forests of Solan Forest Division (HP). *Indian Journal of Ecology*, *36*(1), 1-5.
Sheikh, M. I. (1993). *Trees of Pakistan*. Pakistan. National book foundation, Islamabad.
Singh, S. P., Arish, B., & Zobel, B. (1994). Biomass, productivity, leaf longevity and forest structure in the Central Himalaya. *Ecological Monographs*, *64*(4), 401−421.
Smith, J. E., & Heath, L. S. (2004). Carbon stocks and projections on public forestlands in the United States, 1952–2040. *Environmental Management*, *33*, 433– 442.

Sun, X., Zhang, X., Zhang, S., Dai, G., Han, S., & Liang, W. (2013). Soil nematode responses to increases in nitrogen deposition and precipitation in a temperate forest. *Plos One*, *8*, e82468 doi:10.1371/journal.pone.0082468

Tahir, M., Imam, E., & Hussain, T. (2013). Evaluation of land use/land cover changes in Mekelle city, Ethiopia using remote sensing and GIS. *Computational Ecology and Software 3*(1), 9-16.

Wei, X., Wu, H., Meng, H., Pang, C., & Jiang, M. (2015). Regeneration dynamics of Euptelea pleiospermum along latitudinal and altitudinal gradients: Trade-offs between seedling and sprout. *Forest Ecology and Management*, *353*, 232-239.

World Bank. (2015). *Forest area (% of land area), World Bank open data.* Retrieved from https://data.worldbank.org/indicator/AG.LND.FRST.ZS.

World Wide Fund [WWF]. (2009). Boundary delineation of Margallah Hills National Park (2009) GIS Laboratory, WWF – Pakistan.

Zheng, D., Heath, L. S., Ducey, M. J., & Smith, J. E. (2011). Effects of land use/cover change and harvests on forest carbon dynamics in northern states of the United States from remote sensing and inventory data: 1992–2001. *Forest Science*, *57*(6), 525-534.