DENDROCHRONOLOGICAL STUDIES IN NEPAL: CURRENT STATUS AND FUTURE PROSPECTS

NARAYAN PRASAD GAIRE[1, 2*], DINESH RAJ BHUJU[1] AND MADAN KOIRALA[2]

[1]*Nepal Academy of Science and Technology, Khumaltar, Lalitpur, Nepal. GPO Box 3323, Kathmandu-Nepal.*
[2]*Central Department of Environmental Science, Tribhuvan University, Kirtipur, Kathmandu-Nepal.*
Corresponding author e-mail: npgaire2007@gmail.com

Abstract

This study aims to know the current status of various aspects of tree ring (dendrochronological) studies in Nepal and assess its future prospects. The first tree ring research in the country was carried out in 1970s, after which a steady progress is seen till date with only 56 tree ring studies reported in published and unpublished research reports, thesis and journal articles. Studies have covered some 15 tree species in which the most favored tree for the study has been *Abies spectabilis* and the most widely used parameter for analysis has been the ring width. The longest chronology for Nepal was build from *Tsuga dumosa* with 1,141 years that extended from 856 AD to 1996 AD. On climatic reconstruction, three studies were found that covered temperature from 1546 AD to 1991 AD. Past studies have covered areas like dendroclimatology, dendroecology, dendroarchaeology and stable isotopes in dendrochronology. By geographic coverage, 22 districts out of 75 in the country have been covered, and they are mostly from high altitudes. Recent dendroecological studies have revealed an upward shift of *A. spectabilis* at treeline as well as differential regeneration pattern of treeline forming species in east, central and western Nepal of Himalaya. When analyzed by participation, 50% of the total studies up to now were carried out by Nepali researchers, 29% by foreign researchers and 21% in joint endeavors. For future, a potential of application tree ring study in wider aspects including dendrohydrology, dendroentomology, geomorphology and glaciology with large spatial coverage of the country is seen.

Introduction

Dendrochronology (word derived from Greek dendron, "tree limb"; khronos, "time"; and, -logia-study) is defined broadly to include all studies where the annual growth layers have been assigned to or are assumed to be associated with specific calendar years (Fritts, 1976; Speer, 2010). Dendrochronology or tree-ring dating is the scientific method of dating based on the analysis of patterns of tree-rings. Dendrochronology can date the time at which tree rings were formed, in many types of wood, to the exact calendar year. It is the interdisciplinary science with wider applications. It has several sub-discipline focused in particular area like dendroclimatology, dendroarchaeology, dendroecology, etc.

Dendrochronology is based on some basic principles and concepts like: The Uniformitarian Principle, Principle of Limiting Factor, Concept of Ecological Amplitude, Site selection, Sensitivity, Cross Dating, Repetition, Standardization, Modeling growth- environmental relationships, and Calibration & Verification (Fritts, 1976). Tree rings are an exceptionally valuable source of paleo-climatic information and tree ring data can be used to reconstruct the yearly variations in climate that occurred prior to the interval covered by direct climatic measurements. Tree rings can also be used to establish the year in which an event such as occurrence of an earthquake, landslide, volcanic eruption, or fire and even the date when a panel of wood cut, as long as the event involved the maiming or killing of a tree (Fritts, 1976). The climate phenomena seen through tree rings have spatial scales from a few hectares to a hemisphere, and temporal scales from the few hours of an ice-storm, through decades of drought, to centuries of changed global atmospheric circulation (Hughes, 2002). Tree rings are the most important and widely used sources of long-term proxy climatic data.

Dendrochronology is a young discipline in the realm of sciences with the first Laboratory of Tree-Ring Research established at the University of Arizona in 1937 (Fritts, 1976; Speer, 2010). A. E. Douglass, the founder of the Laboratory of Tree-Ring Research at the University of Arizona is taken as father of dendrochronology (Fritts, 1976). In spite of its recent modern history, the idea that tree produce annual rings had been suggested since time of Theophrastus in 322BC (Studhalter, 1956, cited in Speer, 2010). Dendrochronology is very popular discipline in present context. In the Hindu Kush Karakoram Himalayan region, the history of the subject especially for climate reconstruction is very young as compared to other region. Studies on tree rings in India in forestry aspects such as the evaluation of growth rates, wood productivity and quality, or rotation cycles have been recorded since long back (Gamble, 1902 cited Bhattarcharyya and Shah, 2009), but systematic tree-ring research based on accurate dating of long sequences of growth rings had only been started since the end of the 1980s (Bhattarcharyya and Shah, 2009). In Pakistan the field of dendrochronology seems to be started its step during 1980s (Ahmed, 1989). In case of Nepal collection of tree cores is started at the end of 1970s, however, institutional study is started much later.

The existence of natural microclimate gradients on mountains at high elevations offers one way in which a better understanding of species responses to small changes in climate can be obtained and enables potential plant responses to future climate changes to be evaluated (Liu *et al*., 2006). The highlands of south-central Asia possess a diversity of natural archives (e.g. lake sediments, loess, tree rings, ice cores, glacier fluctuations, geomorphologic features, and palaeobotanical fossils) from which long detailed palaeoclimatic records might be developed (Cook *et al*., 2003). Wide array of habitats representing major biomes of the world in graded climates in mountainous topography of Nepal and cultural diversity of the country provides a great potential in multidimensional tree ring research. This study tries to disclose the various aspects of so far conducted tree ring studies from Nepal including type of methodology used, temporal and spatial coverage of studies, studied species, chronology length, scope of study and research collaboration.

Materials and Methods

This paper is prepared by reviewing the published and unpublished literatures which deals with tree ring researches in Nepal. Literatures were searched by using some key words like tree ring, dendrochronology, dendroclimatology, dendroecology, dendroarchaeology in Nepal. In this study literature published (also conference proceeding, abstract, Thesis, projects) up to the end of August 2012 is incorporated. Similarly, for ongoing research, those studies which were carried out with close contact of NAST's dendrolab were also included.

Results and Discussion

Among the several proxy records tree-ring studies provides high-resolution climate. Based on several earlier work and many other recent publication it has been noted that there is a rapid progress in tree-ring analysis on its multifarious applications especially its potentiality on climatic reconstruction. In Nepal, a total 56 un/published researches or literatures based on tree-ring analysis has been found. Various aspects of tree ring studies covered in Nepal are analyzed in following sub headings.

Methodological aspect: In methodological aspect so far conducted studies have covered wider aspects. Most of the studies, almost all Nepali researchers, have used ring width parameter as a tool for past dendrochronological studies in Nepal. Some studies (Kobayashi *et al*., 2002; Sano *et al*., 2002, 2005; Bräuning, 2004) have used wood densitometry (X-ray densitometry) technique to calculate the density of early wood and late wood of each tree ring which have added the number of parameter that can be used in dendrochronological studies and also the quality of the research. Only two studies (Sano *et al*., 2010, 2012) were found which used stable isotope in tree ring for the past climate change study in Nepal. No one study was found using wood anatomical features for past environmental studies. These studies suggested that combination of wood densitometry and isotope analysis, besides ring width parameter, is best and appropriate approach for tree ring studies in Nepal (Bhattacharyya *et al*., 1992; Sano *et al*., 2005) because it not only improve the quality of research but also increase predictor variable in tree ring research.

Temporal aspect of study: Fig.1 presents temporal aspect of dendrochronological studies carried out in Nepal. Initially dendrochronological studies in Nepal was started by foreign researchers. According to the Bhattacharyya *et al.* (1992), earlier tree-ring collections in Nepal initiated in the late-1970s (1979-1980) by Rudolf Zuber who collected tree ring samples of diverse species and habitats. However, first tree ring related research from Nepal was published in 1990 by Suzuki. Bhattacharyya *et al*. (1992) extended Dendro study in Nepal by collecting large scale wood samples and described ten ring width based chronologies and reviewed the prospects for further dendroclimatic work in Nepal, they also pointed the good potentiality of some conifer tree species like: *Pinus wallichiana, Cupressus dumosa, Cedrus deodara*, *P. roxburghii*, *and Abies spectabilis* for dendroclimatic study. Later this work is further extended by Cook's team. Cook *et al*. (2003) used Zuber collected core samples as well Dr Burghardt Schmidt collected sample from living trees and archaeological wood in the dry inner valleys of north-central Nepal to develop master chronologies of various species. They carried out extensive and intensive sampling in Nepal and developed 32 tree ring chronologies using different tree species (Cook *et al*., 2003). Research publications on the Dendro study in Nepal are seemed to be increased slowly at beginning while faster in recent years (Fig.1). At 2002 the publications on tree ring studies from Nepal was increased and reached to six in which contribution of studies by Japanese researchers is crucial besides few Nepali researchers (Furuta *et al.,* 2002, Khanal and Rijal, 2002; Sano *et al.,* 2002a, b; Yasue *et al.,* 2002). Studies after 2010 increased rapidly mainly due to the contribution of Nepali researchers after the establishment of the first Dendro lab in Nepal Academy of Science and Technology in 2009. Increasing trend in number of studies and publication on tree ring is continue in 2012; at this period more than 10 tree ring researches in different parts of the country were active.

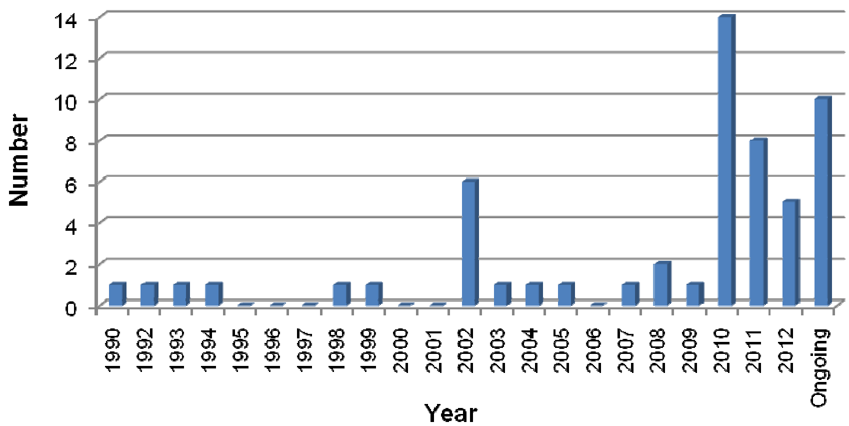

Fig.1. Number of dendrochronological studies by year of publications.

Spatial coverage of studies

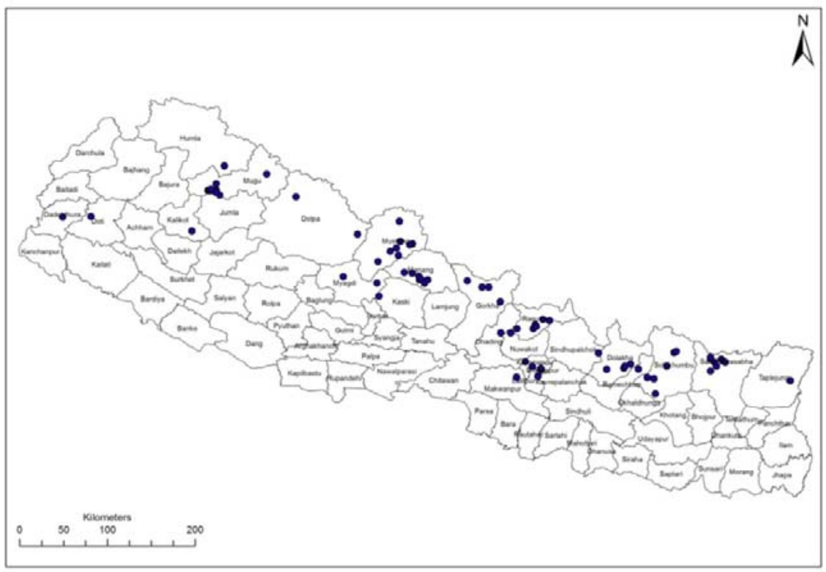

Fig. 2. Distribution of sampling sites for dendrochronological studies in Nepal.

Dendrochronological studies have been extended from far east to far west of Nepal Himalaya (Fig.2). So far these studies covered more than 22 districts of middle mountain to higher Himalaya of Nepal. Altitude of these studies were ranged from about 1000m to 4300 masl. Tree-ring studies carried out so far in the Nepal Himalaya region are mainly restricted to the lower temperate and sub alpine forests growing below treeline (egs. Suzuki, 1990; Bhattacharyya *et al*., 1992; Cook *et al*., 2003; Bräuning , 2004; Sano *et al.,* 2005, Chhetri and Thapa, 2010, Ghimire, 2012). Few tree ring studies are found from treeline of Nepal Himalaya (egs. Bhuju *et al.,* 2010, Gaire *et al.,* 2011) and subtropical region (Regmi, 1998). But, no one study was conducted in Terai and Siwalik/Churiya area comprising tropical and subtropical region of the country, which is consistent with global trend in neglected tropical area. Many studies are concentrated on some pocket area or region in which Langtang region come in first from where more than 10 studies have been carried out. So there is a great discrepancy in the spatial coverage of the tree ring studies in Nepal.

Species coverage and chronology length: So far 15 tree species are used in Dendrochronological studies in Nepal. Wood sampling of following species like *Abies spectabilis, Acer sp, Alnus nepalensis, Betula utilis, Cedrus deodara, Juniperus indica, Juniperus recurva, Larix potanini, Picea smithiana, Pinus roxburghii, Pinus wallichiana, Rhododendron campanulatum, Sorbus sp, Tsuga dumosa, Ulmus wallichiana*, etc have been collected. However, tree ring chronologies can be established only for nine species namely *Abies spectabilis,* *Betula utilis, Cedrus Deodara, Juniperus Recurva, Picea smithiana, Pinus roxburghii, Pinus wallichiana, Tsuga dumosa, Ulmus wallichiana* (Suzuki, 1990; Bhattacharyya *et al*., 1992; Cook *et al*., 2003). Among these species, *Abies spectabilis* is most studied tree species which can be found in about 75% literatures followed by *Betula utilis* (22.9%), *Pinus wallichiana* (16.7%) and *Pinus roxburghii* (12.5%). Wide use of *Abies spectabilis* may be due to clear annual ring, easy for core sampling and distribution in wider areas. Most of these studied were confined to soft wood or conifer species, while few studies were conducted in broad leaved trees like *Betula, Rhododendron, Alnus*, etc. Therefore there is great prospect of multi-aspect tree ring studies in Nepal using various new tree species growing in diverse environment. No one studied shrub species of Nepal which may also an area of possibility in future.

Table 1. Length of longest ring width chronologies of selected tree species from Nepal.

Species	Chronology length	Duration(AD)	References
Abies spectabilis	603	1395-1997	Cook *et al*., 2003
Betula utilis	458	1552-2009	Dawadi *et al.,* 2012
Cedrus deodara	264	1714-1978	Bhattacharyya *et al*., 1992
Juniperus recurva	582	1717-1998	Cook *et al*., 2003
Picea smithiana	373	1628-2000	Furuta *et al*., 2002
Pinus roxburghii	297	1683-1979	Bhattacharyya *et al*., 1992
Pinus wallichiana	694	1303-1996	Cook *et al*., 2003
Tsuga dumosa	1141	856-1996	Cook *et al*., 2003
Ulmus wallichiana	432	1566-1997	Cook *et al*., 2003

While looking at the annual ring width chronologies length of different species, it varies from species to species (Table 1). Though different researchers developed varied length of chronologies, here, we only present the longest chronology length for available species. Longest chronology for Nepal was build for *Tsuga dumosa* which has the length of 1141years and extends from 856AD to 1996AD. For *Abies spectabilis* 603 years long (1395-1997AD), *Pinus wallichiana* 694 yrs (1303-1996AD) and *Juniperus recurva* 582 years (1717-1998) long chronologies have been built up. The length of these chronologies may be extended back by further research.

Scope of study: Dendrochronology is a versatile discipline with wider applications (Fritts, 1976; Speer, 2010). With time and discoveries of the new technology, the application of tree ring has been increased. There are a number of sub disciplines of dendrochronology having focused in particular areas of environment like Dendroclimatology, Dendroecology, Dendroentomology, Dendroseismology, Dendrogeomorphology, Dendrohydrology, Dendroglaciology, Stable isotopes in dendrochronology, Wood anatomy in dendrochronology, Dendroarchaeology, and many more.

The major sub discipline of dendrochronology is Dendroclimatology which involves the reconstruction of past climatic variations of particular area. Most of the tree ring researches in Nepal are carried out with the aim of reconstructions of past climatic variations using tree rings, however, only few studies have succeeded to reconstruct past climate (Cook *et al.,* 2003; Sano *et al.,* 2005, 2012). Most of the research studies were confined to the response function analysis or tree growth–climate relationship analysis (egs. Suzuki, 1990; Bhattacharyya *et al*., 1992; Bräuning, 2004; Chhetri and Thapa, 2010; Tenca and Carrer, 2010; Dawadi *et al*., 2012). The main reasons of limitation in response function analysis is the lack of good quality climatic data with sufficient temporal coverage. The first published climatic reconstruction using tree ring data from Nepal on international journal was by Cook *et al.* (2003). They reconstructed past temperature of two seasons: February–June (1546–1991) and October–February (1605–1991) (Fig. 3). Each reconstruction indicates the occurrence of unusually cold temperatures in 1815–22, which coincides with the eruption of Tambora in Indonesia. After adjustment of probable missing multi-centennial temperature variance to each reconstruction, the resulting 'adjusted' reconstructions strongly reflect patterns of temperature variability associated with Little Ice Age cooling and warming into the 20th century, with the October–February season exhibiting the strongest increase in temperature over the past ∼400 years. Only the October–February season shows any evidence for late- 20th century warming, whereas February–June temperatures have actually cooled since 1960 (Cook *et al*., 2003). Later, Sano *et al.* (2005) reconstructed the climate of western Nepal for the past 249 years by using relationship between climate and ring width & wood density of *Abies spectabilis*; result shows a warming trend from 1750s until approximately 1790, followed by cooling until 1810, then by a gradual warming trend extending to 1950, and a notable cold period continuing up to the present (Fig.3). Recently a $\partial^{18}O$ tree-ring chronology by Sano *et al.* (2012) has shown increasing aridity over the past 223 years in the Nepal Himalaya.

Dendroecology is an important sub discipline of dendrochronology. In this category studies related to impact of climate variability on stand dynamics and treeline dynamics as well as different aspect of forest management like fire frequency, pest infestations, annual increment of trees, etc, can be studied. Some studies related to this field were also conducted in Nepal. Most of them were focused at treeline (eg. Gaire, 2008; Dhakal, 2009; Ansari, 2010; Suwal, 2010, Bhuju *et al.,* 2010; Bista, 2011; Gaire *et al.,* 2011; Ojha, 2012). These studies have also focused on regeneration; some studies found differential regeneration and growth rate in treeline and timberline of Khumbu region (Bhuju *et al.* 2010) and some found different regeneration above and below treeline (Suwal, 2010; Bhuju *et al.,* 2010). Various studies revealed the consistent upward shifting of *Abies spectabilis* with a range of 1.56 to 3.4m per year in different region of the Nepal (Ansari, 2010; Suwal, 2010; Gaire and Bhuju, 2010). Future of dendrochronology is dendroecology because of practical implication of the knowledge derived from the tree-ring studies in various issues like climate change adaptation and forest or ecosystem management.

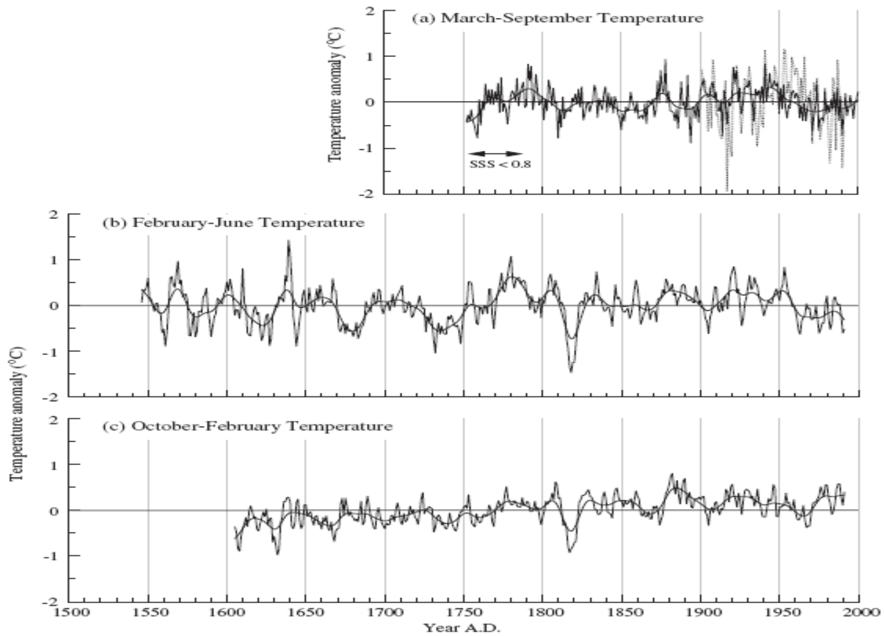

Fig.3. Reconstructed mean temperatures in Nepal, as deviations from the long-term means: (a) March–September with observed data (dotted line) (in Sano *et al.* 2005) (b) February–June and (c) October–February (in Cook *et al.* 2003).

Dendroarchaeology involves in the study of past cultures, civilizations as well as past climate by using tree ring from the archaeological sites (Fritts, 1976). This kind of studies was carried out in Nepal, mainly in the initiative of German scientists like: Dr. Burghardt Schidimit, Dr. Achim Brauning, Thomas wazny etc and Nepali researcher like Kuber Malla, during 1980s (Schmidt, 1992-93; Gutschow, 1994; Schmidt *et al.,* 1999). They have carried out extensive sampling of tree cores from archaeological excavations, old houses, monasteries and castles of high altitude region of the country like Mustang, Dolpa and Khumbu. From the study of tree ring of pine wood sample used in the monastery of Muktinath, Schidimit (1992-93) found that the woods used in the construction of the monastery (the youngest tree ring before being chopped down) was felled in 1906 and a specimen from the foundations of the kings palace in Dzarkot was found to be felled in 1512. Schmidt *et al*. (1999) established a master chronology for Nepal covering the time-span between AD 1324 to 1997 which can provide important information about the history and dynamics of the local settlements, local architecture, castles and monasteries along the old famous trade route between Tibet and India. Their result indicated the wider prospects of the dendroarchaeological studies in Nepal. Bhuju and Gaire (2010) studied the old pine stand of Kathmandu valley (Sallaghari Bhaktpur, Singhdurbar, Thapathali) to find the plantation history of these location and they found about 150 years old trees.

Stable isotopes used in dendrochronology (Stable isotopes in trees) i.e. different stable isotopes trapped in the tree rings can provide valuable information of the past climate or environmental change. Studies of this isotope analysis in trees rings are very limited in Nepal and only two publications by Sano *et al.* (2010, 2012) was found on this aspect. Sano *et al*. (2010) developed a 50-year tree-ring $d^{18}O$ chronology of *Abies spectabilis* growing close to the treeline (3850masl) in the western region of Nepal Himalaya. From the response- function analysis with ambient climatic records they found that tree-ring $\delta^{18}O$ is primarily governed by rain fall during the monsoon season (June–September). Extreme dry years identified in instrumental weather data are also detected in the d^{18}O chronology. Tree-ring d^{18}O is much more sensitive to rainfall fluctuations than other tree-ring parameters such as width and density typically used in dendroclimatology. El Nino and ENSO phenomenon can also be studied by using this technique. A tree-ring δ^{18}O chronology of *Abies spectabilis* from the Nepal Himalaya revealed increasing aridity over the past 223 years extended from ad 1778 to 2000 (Sano *et al.*, 2012). Though this technique gives more in-depth knowledge, due to lack of instrument in Nepal, development of this field will depend on the collaborations with foreign researchers.

Looking at the climate growth response, different researchers found different response at local level, however, they got common signal in their chronologies for certain pointer year. From study around Lake Rara, and performing a multiple regression analysis between ring widths and seasonal precipitation, Suzuki (1990) found that rain from May to August primarily affected the tree growth and that from September to December in the previous year secondarily. Ring width of birch from Dolpo Himalayas was highly correlated with summer temperature of the summer prior to growth, whereas ring width of fir was strongly correlated with temperature during the winter before the growing season as revealed by Brauning (2004). A study of *Abies spectabilis* from Humla, Sano *et al.* (2005) found that the ring width was correlated negatively with March–May (pre-monsoon) temperature and positively with March–May precipitation, while the minimum density was correlated positively with March–July temperature and negatively with March–May precipitation. These results indicate that the ring width and minimum density are primarily controlled by the pre-monsoon temperature and precipitation which is consistent to Suzuki (1990), while the latewood density by the late monsoon temperature (Sano *et al.* 2005).

Though wood anatomy act as an indicator of environmental factors, studies on Wood anatomy in dendrochronology was not carried out from Nepal. No study was conducted in Dendroseismology, Dendrogeomorphology, Dendroentomology, Dendrohydrology and Dendroglaciology in Nepal, though these fields also have huge potential in Nepal.

Research collaboration: Looking at the literature on the basis of nationality of the researchers, 50% of the studies were carried out by Nepali researchers followed by 29% by foreign researchers (Fig. 4). Only 21% studies have been carried out by collaborating each other. Among the non native researchers, contribution of American, Japanese, German and Indian researchers to foster the tree ring research in Nepal is high. In independent study by Nepali researchers, thesis studies contributed mainly.

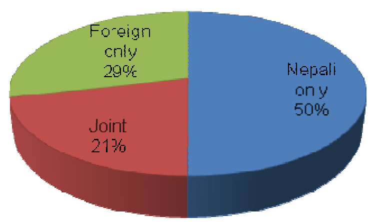

Fig.4. Tree ring research by the nationality of the researchers.

Looking at the temporal aspect of research collaboration, in the beginning, involvement of the Nepali in tree ring research was mainly as tourist guide or porter of foreign research expedition team. Only few Nepali have been involved in researchers' team. Looking at the authorship of the publications clearly shows this. After 2005, mainly after 2008, the contribution by Nepali researchers was found higher than that of non native researchers which was just opposite direction at before, which shows increased concern and interest of Nepali researchers on this field. Research collaboration is increased in the recent years (Fig. 5), however, which is still unsatisfactory. But, looking at those researches which are in progress, the collaboration is high as large numbers of the ongoing researches are carried out by the Nepali students studying in the foreign universities.

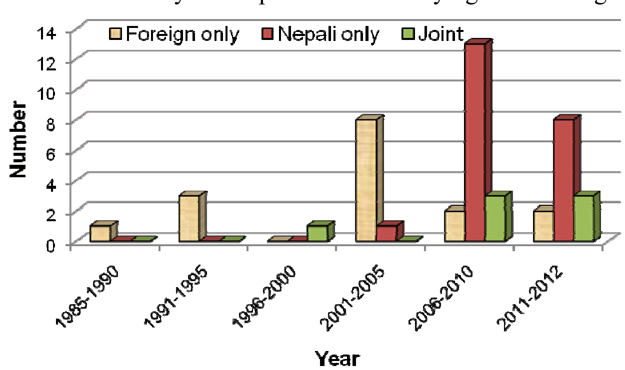

Fig.5. Research collaboration with time.

Prospects and challenges of future tree ring studies in Nepal: Mountainous country representing the major biome of the world in small geographical area, Nepal has ample opportunities for the multitude aspects of dendrochronological research. Existence of diverse forests and vegetation ranging from tropical forest to temperate forest and subalpine meadows, large number of rivers and glaciers, changing land use pattern may provide good platform for diverse research in the context of climate change, its mitigation as well as adaptation on it. It provides opportunities to work not only in the dendroclimatological aspect but it also has opportunities to link tree ring data to the cultural and land use change.

There are some of challenges of tree ring research in Nepal.

- Further expansion of dendrochronological studies in tropics as well as in new thematic areas like pollution or dendrochemistry, dendroentomology, etc.
- Expansion of the temporal and spatial replications of tree rings for the study of past environmental changes.
- Study of abrupt events (earthquakes, landslides, fires, climatic extremes) that have large impacts on society.
- Better understanding of vulnerabilities of humans to climate change.
- So far conducted dendro studies from Nepal covers dendroclimatology, dendroarchaeology, and dendroecology and isotope analysis, however, native researchers are engaged mostly on dendroecology and just response-function analysis. The challenge is how to strengthen the professional capabilities of the Nepali researchers to cover other aspects.
- Increment of investment of the government and private organizations in the field of research and development, particularly in the science and technology. Collaboration with and support from various organizations is very crucial.

Conclusion

This study reviews and summaries the result of tree-ring studies carried out (up to August 2012) from Nepal. A total of 56 studies (published and unpublished) were reported from Nepal, among them, 50% were carried out by Nepali researchers, 29% by foreign researchers and 21% studies were carried out in joint endeavors. Studies have covered more than 15 tree species and revealed several species like *Abies spectabilis, Betula utilis, Cedrus deodara, Juniperus indica, Juniperus recurva, Picea smithiana, Pinus roxburghii, Pinus wallichiana, Tsuga dumosa, Ulmus wallichiana*, which were promising for dendrochronological studies in Nepal. Longest chronology from Nepal was build using Tsuga dumosa which was 1141years long and extended from 856AD to 1996AD. Only three climatic reconstructions (temperature) studies were published in international journal covering different time period of seasons: February–June (1546–1991), October–February (1605–1991) and March–September temperature (1752-2000). The scope of dendroclimatology, dendroecology, dendroarchaeology and stable isotopes is carried out in 22 districts of the country. Large spatial coverage of country is still not explored. Therefore Dendrochronological studies should be extended in other areas of the country.

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References

Ahmed, M. (1989). Tree-Ring chronologies of *Abies pindrow* (Royle) Spach from Himalayan Regions of Pakistan. *Pak. J. Bot*. 21(2): 118-127.

Ansari, A.B. (2010). Climate change and vegetation shift of *Abies spectabilis* D. Don in the tree line areas of Sankhuwasava district of eastern Nepal. In: *Abstracts*: International Conference on Biodiversity, Livelihood and Climate Change in the Himalayas, Kathmandu Nepal (P. K. Jha *et al* eds.), Central Department of Botany, T.U., kirtipur, pp-182.

Bhattacharyya, A., Lamarche, V.C.JR and Hughes, M.K. (1992). Tree ring chronologies from Nepal. *Tree Ring Bulletin* 52: 59-66.

Bhattacharyya, A. and Shah, S.K. (2009). Tree-ring studies in India: past appraisal, present status and future prospects. *IAWA Journal* 30(4): 361-370.

Bhuju, D.R. (2007). Climatic and human impact on High Altitude Forests in Nepal Himalaya. In: Abstracts of National conference on Environment (22-24 June, 2007). Kathmandu, Nepal.

Bhuju, D.R., Carrer, M., Gaire, N.P., Soraruf, L., Riondato, R., Salerno, F. and Maharjan, S.R. (2010). Dendroecological study of high altitude forest at Sagarmatha National Park, Nepal, In: Jha, P.K. and Khanal, I.P. (Eds.), Contemporary research in Sagarmatha (Mt. Everest) region, Nepal, Nepal Academy of Science and Technology, Lalitpur, Nepal, pp.119-130.

Bhuju, D.R. and Gaire, N.P. (2010). Plantation history of old pine stand of Kathmandu valley. Research report. Nepal Academy of Science and Technology, Lalitpur.

Bista, R. (2011).Treeline Ecotonal Dynamic: A Case Study from *Pinus wallichiana* Forest in Ngawal, Manang, North-Central Nepal. MSc. Dissertation, Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.

Bräuning, A. (2004). Tree-ring studies in the Dolpo-Himalya (western Nepal). In: E. Jansma, A. Bräuning, H. Gärtner, and G. Schleser, eds., *Tree Rings in Archaeology, Climatology and Ecology* 2 : 8-12.

Chhetri, P.K. (2008). Potential of Dendrochrology in Climate change study in Nepal. MSc thesis submitted to Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.

Chhetri, P.K. and Thapa, S. (2010).Tree Ring and Climate change in Langtang National Park, Central Nepal. *Our Nature* 8: 139-143.

Cook, E.R., Krusic, P.J. and Jones, P.D. (2003). Dendroclimatic Signals in Long Tree- Ring Chronologies from the Himalayas of Nepal. *International Journal of Climatology* 23: 707-732.

Dawadi, B., Liang, E., Tian, L., Devkota, L.P. and Yao, T. (article in press). Pre-monsoon precipitation signal in tree rings of timberline *Betula utilis* in the central Himalayas. Quaternary International (2012), doi:10.1016/j.quaint.2012.05.039.

Dhakal, Y.R. (2009). Forest ecology and tree ring pattern at the treeline of Langtang National Park, Nepal Himalaya. A MSc. dissertation submitted to Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.

Furuta, F., Sano, M., Kobayashi, O. and Sweda, T. (2002). Response of Picea smithiana to climate in northwestern Nepal. In: Proceedings of Geothermal / Dendrochronological Paleoclimate Reconstruction across Eastern Margin of Eurasia, 2002 International Matsuyama Workshop, Matsuyama, Japan, ed. Yamano, M., Nagano, T., Sweda, T.P. 22-26.

Gaire, N.P. (2008). Ecology and dendroclimatology of treeline forest in Langtang National Park, Nepal Himalaya. A MSc. dissertation submitted to Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.

Gaire, N.P. and Bhuju, D.R. (2010). Impact of Climate Change in Treeline Ecotone of Manaslu Conservation Area, Nepal Himalaya. Abstracts. (P.K Jha *et al*. eds.). International Conference on Biodiversity, Livelihood and Climate Change in the Himalayas (12-14 December 2010, Kathmandu Nepal. Central Department of Botany, TU, Kirtipur, Kathmandu. pp 158-159.

Gaire, N.P., Dhakal, Y.R., Lekhak, H.C., Bhuju, D.R. and Shah, S.K. (2011). Dynamics of *Abies spectabilis* In relation to climate change at the treeline ecorone in Langtang National Park. *Nepal Journal of Science and Technology* 12: 220-229.

Gamble, J.S. (1902). A manual of Indian timbers. Sampsonlow, Marston and Co., London.

Ghimire, R. (2012). People’s perception and dendroclimatic evidence on climate change:a case study on Shivapuri-Nagarjun National Park. MSc. Dissertation, Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal, 2011.

Gutschow, N. (1994). Kagbeni: structural analysis of dendrochronological data. *Ancient Nepal* 136: 23-50.

Hughes, M.K. (2002). Dendrochronology in climatology ± the state of the art, *Dendrochronologia,* 20(/1-2): 95-116.

Khanal, N.R. and Rijal. S.P. (2002). Tree ring chronology from Ganesh Himal area, Central Nepal. In: Proceedings of Geothermal/Dendrochronological Paleoclimate Reconstruction across Eastern Margin of Eurasia, 2002 International Matsuyama Workshop, Matsuyama, Japan, Eds.: Yamano, M., Nagano, T., Sweda, T.P. 12-19.

Kobayashi, O., Sano, M. and Sweda, T. (2002). Climate response of Tsuga dumosa densitometric variables from Myagdi Khola, Nepal. In:Geothermal/Dendrochronological paleoclimate Reconstruction across Eastern Margin of Eurasia, 2002 International Matsuyama Workshop, Matsuyama, Japan.

Lekhak, H. (2011). Forest ecology and tree ring chronologies at the treeline of Langtang National Park, Nepal Himalaya. MSc. Dissertation, Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.

Liu, L., Shao, X. and Liang, E. (2006). Climate Signals from Tree Ring Chronologies of the Upper and Lower Treelines in the Dulan Region of the Northeastern Qinghai-Tibetan Plateau. *Journal of Integrative Plant Biology* 48(3): 278-285.

Ojha, K. (2012). Impact of climate change on tree-limit rise in Langtang national park of central Himalaya, Nepal. MSc. Dissertation, Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.

Regmi, D. (1998). Climate and Tree growth of Pines in Kulekhani area, mid hills of Nepal. M.A. thesis submitted to central department of geography, TU, Kirtipur, Nepal.

Sano, M., Furuta, F., Kobayashi, O. and Sweda, T. (2002a). Paleoclimate reconstruction for western Nepal based on Abies spectabilis tree-ring width and density. In: Proceedings of Geothermal/Dendrochronological Paleoclimate Reconstruction across Eastern Margin of Eurasia, 2002 International Matsuyama Workshop, Matsuyama, Japan, ed. Yamano, M., Nagano, T., Sweda, T. P. 2-11.

Sano, M., Furuta, F., Kobayashi, O. and Sweda, T. (2002b). Tree-ring based reconstruction of eastern Nepal climate back to A.D. 1702. In: Proceedings of geothermal /Dendrochronological Paleoclimate Reconstruction across Eastern Margin of Eurasia, 2002 International Matsuyama Workshop, Matsuyama, Japan, ed. Yamano, M., Nagano, T., Sweda, T.P. 27-36.

Sano, M., Furuta, F., Kobayashi, O. and Sweda, T. (2005). Temperature variations since the mid-18th century for western Nepal, as reconstructed from tree-ring width and density of *Abies spectabilis*. *Dendrochronologia* 23: 83-92.

Sano, M., Sheshshayee, M.S., Managave, S., Ramesh, R., Sukumar, R. and Sweda, T. (2010). Climatic potential of delta o 18 of *Abies spectabilis* from the Nepal Himalaya. *Dendrochronologia* 28: 93-98.

Sano, M., Ramesh, R., Sheshshayee, M.S. and Sukumar, R. (2012). Increasing aridity over the past 223 years in the Nepal Himalaya inferred from a tree-ring δ18O chronology. *The Holocene* 22(7): 809-817.

Schmidt, B. (1992-93). Dendrochronological Research in Southern Mustang Mustang Ancient Nepal 130-133: 20-33.

Schmidt, B., Wazny, T., Malla, K., Höfs, E. and Khalessi, M. (1999). Chronologies for historical dating in high Asia/Nepal. In: *R.* Wimmer and R.E. Vetter, eds., Tree-Ring Analysis: Biological, Methodological, and Environmental Aspects. CABI Publishing, Oxon, United Kingdom 205-211.

Shrestha, N. (2012***).*** Response of *Pinus wallichiana* Tree Ring to Climate Variability in Mustang, Nepal. MSc. Dissertation, Institute of Forestry, Office of Dean, Tribhuvan University, Kathmandu, Nepal.

Speer, J.H. (2010). Fundamentals of Tree ring Research. The University of Arizona Press, Tucson.

Studhalter, R.A. (1956). Early history of crossdating. *Tree Ring Bulletin* 21(1-4): 31-35.

Suwal, M.K. (2010). Tree species line advance of Abies spectabilis in Manaslu Conservation Area, Nepal Himalaya. M.Sc. Thesis. Central Department of Botany, Tribhuvan University, Kathmandu Nepal.

Suzuki, E. (1990). Dendrochronology in coniferous forests around Lake Rara, west Nepal. *Botanical Magazine Tokyo* 103: 297-312.

Tenca, A. and Carrer, M. (2010). Growth climate response at high elevation: comparing Alps and Himalayas. *Tree Rings in Archaeology, Climatology and Ecology* 8: 89-97.

Udas, E. (2009). Influence of climate variability on the growth performance of Abies spectabilis at tree line of West-central Nepal. Master Thesis, University of Greifswald, Germany.

Yasue, K., Noda, M., Kobayashi, O., Kato, T. and Sweda, T. (2002). Dendroclimatological potential of *Abies spectabilis* from Khurpudada pass, Ganesh Himal, Central Nepal. In: Proceedings of Geothermal/Dendrochronological Paleoclimate Reconstruction across Eastern Margin of Eurasia, 2002 International Matsuyama Workshop, Matsuyama, Japan, ed. Yamano, M., Nagano, T., Sweda, T.P. 20.