Tree Ring Analysis of *Tectona grandis* L.f. in Gujarat

Aparna Rathore* and Yogesh T Jasrai

Abstract
Climate of the earth is continuously changing due to natural and anthropogenic reasons. For predicting future climate it is imperative to know how climate changed in the past, especially during the past few centuries. High resolution long term climate data during the recent past about 1000 years are needed to understand natural climate variability and the magnitude of human impact on it. Terrestrial proxies available for climate reconstruction are ice cores, lake sediments, corals, speleothems and tree rings. Among these tree rings have specific advantages: they have a wide geographic distribution, are annually resolved, show a continuous record and are easily dated by ring-counting. With their high resolution and reliability, tree rings play an important role in global change studies.
In the present study tree ring samples were collected using increment corer from different teak dominant areas of Gujarat and the tree ring widths were correlated with temperature and precipitation data and drought years. The results so obtained show a sharp correlation of the ring width development with the drought years. Hence, the drought condition has a prominent effect on the growth rate of the teak trees.

Key words: Climate change, tree rings, ring width, crossdating, dendrochronology.

INTRODUCTION

Climate of the earth is continuously changing due to natural and anthropogenic reasons. For predicting future climate it is imperative to know how climate changed in the past, especially during the past few centuries. High resolution long term climate data during the recent past about 1000 years are needed to understand natural climate variability and the magnitude of human impact on it **(Bradley *et al.*, 1996; Yadav *et al.*, 2002; Ram *et al.*, 2008).** Terrestrial proxies available for climate reconstruction are ice cores, lake sediments, corals, speleothems and tree rings. Among these tree rings have specific advantages: they have a wide geographic distribution, are annually resolved, show a continuous record and are easily dated by ring-counting. Seasonality in the growth rate of trees driven by variability in the climatic factors can result in well defined growth rings in trees. Individual tree rings faithfully record contemporary climatic signatures hence provide an opportunity to decipher the variation in climatic parameters for a duration equivalent to the life span of the tree **(Managave *et al.*, 2010).**

- ***Aparna Rathore*** *is currently pursuing PhD degree program in Botany at Department of Botany, Gujarat University, Ahmedabad, Gujarat, India. Email: rathoreaparna@ymail.com*
- ***Yogesh T Jasrai*** *is currently Professor and Head, Department of Botany, Gujarat University, Ahmedabad, Gujarat, India.*

In addition, tree ring research can also provide great insights into the mechanisms of climate change **(Briffa *et al.*, 2004).** Tree rings have been used in various applications to reconstruct past climates as well as to access the effect of recent climatic and environmental changes on tree growth. Temperature changes based on the tree ring records suggests that climate swings in the last 1000 years were greater than the IPCC estimates (**Pandey, 2002).**

Teak (*Tectona grandis*) and its significance in Tree Ring Analysis

Teak, Sag, Sagwan is the common name for the tropical hardwood deciduous tree species ***Tectona grandis*** L.f. belonging to the family Verbenaceae. *Tectona grandis* is native to south and south-east Asia, mainly India, Indonesia, Malaysia and Myanmar. *Tectona grandis* is found in a variety of habitats and climatic conditions from arid areas with only 500 mm of rain per year to very moist forests with up to 5,000 mm of rain per year.

Teak (*Tectona grandis*) is one of the few tropical species showing distinct and reliable growth rings and holds potential for reconstructing monsoonal precipitation over India. Annual nature of growth rings in teak trees was established by **Berlage (1931) and Chowdhary (1939).** Several studies **(Berlage, 1931; Bhattacharyya *et al.*, (1992), D'Arrigo *et al.*, 1994, Pumijumnong *et al.*, 1995; Priya and Bhat, (1999), Borgaonkar *et al.*, 2007; Buckley *et al.*, 2007, Shah *et al.*, 2007, Ram *et al.*, 2008)** have reported reconstruction of past climate, especially rainfall, using variations in ring-widths of teak. **Sudheendrakumar *et al.*, (1993)** have observed a bellshaped teak growth curve with higher growth rates during the months of higher rainfall. These studies indicate high potential of *Tectona grandis* in reconstruction of regional climate (monsoon) related parameters (e.g., rainfall, drought frequencies and intensities, ENSO/El Ni˜no, etc.).

The present study deals with the dendrochronological and dendroclimatological analysis of *Tectona grandis* L.F. The tree-ring-width chronologies of teak (*Tectona grandis* L.F.) were analysed from the teak dominated areas of Gujarat (Waghai, Purna, Shoolpaneshwer, Ratanmahal, Jambughoda, Ahmedabad, Gandhinagar, Balaram and Gir) to evaluate their dendroclimatic potential in relation to rainfall, temperature and drought condition over the region.

MATERIAL AND METHOD

Study area

Gujarat is situated at latitude of 20°01' 24.07''N and longitude of 68°04' 74.04''E with a total area of 196,077 km². On the basis of rainfall received Gujarat has been divided into 7 agro-climatic zones. The tree rings were sampled from the agroclimatic zones of Gujarat where teak trees (*Tectona grandis*) are prominent (Fig-1). From the Southern hill zone the tree ring were sampled from Waghai Botanical Garden, Dangs (0.24 km²; 20°45' 26.34''N and 73°29' 58.35''E; 181.66 m a.s.l.) and Purna Wild Life Sanctuary, Dangs (160.84 km²; 20°56' 12.99''N and 73°40' 21.64''E; 390.45 m a.s.l.). From the South Gujarat zone the Teak samples were collected from Shoolpaneshwer Sanctuary, Narmada (607.07 km²; 21°45' 44.34''N and 73°45' 47.60''E; 479.75 m a.s.l.). For these locations the climatic data recorded at Surat Meteorological Station (21°11' 42.86''N and 72°50' 06.76''E; 10.97 m a.s.l.) were used.

From the Middle Gujarat zone the Teak samples were collected from Ratanmahal Sanctuary, Dahod (55.65 km²; 22°29' 37.51''N and 74°04' 55.75''E; 239.88 m a.s.l.) and Jambughoda Sanctuary, Panchmahal (130.38 km²; 22°21' 14.71''N and 73°40' 32.63''E; 184.4 m a.s.l.). For these locations the climatic data recorded at Dahod Meteorological Station (22°49'N and 74°15'E; 305 m a.s.l.) were used.

From the North Gujarat zone the Teak samples were collected from various sites at Ahmedabad (23°02' 10.28''N and 72°32' 48.11''E; 55.78 m a.s.l.), Gandhinagar (23°11' 53.64''N and 72°38' 14.51''E and 75 m a.s.l.) and Balaram Ambaji Sanctuary, Sabarkantha (542.08 km²; 24°18' 23.77''N and 72°46' 49.98''E; 428.24 m a.s.l.). For these locations the climatic data recorded at Ahmedabad (23°03'N and 72°58'E; 53 m a.s.l.), Gandhinagar (23°13'N and 72°38'E; 82 m a.s.l.) and Idar Meteorological Station (23°49'N and 72°59'E; 213 m a.s.l.) respectively were used. From the South Saurashtra zone the teak samples were collected from the Gir Wild Life Sanctuary, Junagadh (1153.42 km²; 21°06' 57.88''N and 70°47' 32.39''E; 289.56 m a.s.l.). For this location the climatic data recorded at Rajkot (22°18'N and 70°48'E; 133 m a.s.l.) was used.

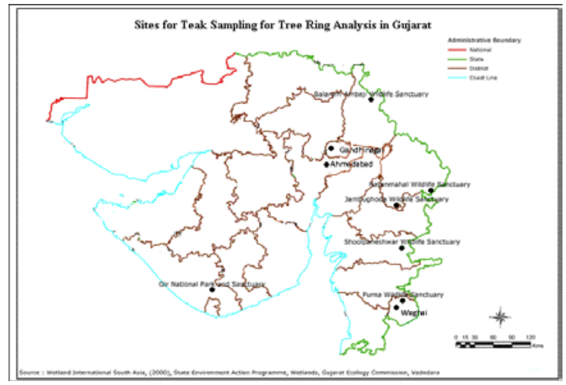

Figure-1: Showing sites of Tree Ring Analysis in Gujarat

For these investigations the climatic data (Monthly rainfall and temperature data) obtained for all the stations of Gujarat from the IMD, Pune has been applied. The average monthly temperatures and monthly precipitation are usually treated as the main factors influencing tree ring formation **(Fritts, 1976; Cook, 1987; Juknys *et al.*, 2002).**

METHOD

Dendroclimatological analysis of *Tectona grandis*

Dendroclimatological investigations were carried out on teak (*Tectona grandis* L.f.) collected from various teak dominant areas in Gujarat (Fig-1). To minimize non-climatic influences on ring growth, only healthy trees with no obvious injury or disease were sampled **(Zhu *et al.*, 2009).** Two tree ring cores per live trees were acquired using a standard non-destructive increment borer at the base or breast height (1.4 m) to remove a 5 mm diameter core from the tree with the aim to extract all the growth-rings present in the tree (Fig-2). Core samples were carefully removed, stored and transferred for laboratory analysis using standard dendrochronological techniques **(Fritts 1976; Ram *et al.*, 2008; Zhu *et al.*, 2009).** The increment bores were air dried and glued onto wooden mounts in transverse position (Fig-2). The transverse surfaces of the cores were cut with a sharp razor and then polished using different grades of sand paper until the cellular details became clear under a hand held microscope **(Di´Az *et al.*, 2001; Yadav *et al.*, 2002).**

Figure 2: Showing method of tree ring analysis. A: Tectona grandis L.F. tree. B: Increment corer. C&D: Showing method of tree ring extraction from teak tree using increment corer. E&F: Showing the tree rings after mounting on wooden mounts and polishing, ready for ring counting and correlation analysis

The tree rings were counted and ring widths were measured using a hand held microscope to a precision of 0.1 mm. Skeleton plot method was used to assign exact year of growth to each and every ring **(Stokes and Smiley, 1968).** The site ring width index chronologies were prepared by averaging all the tree-ring index series over the individual site **(Di´Az *et al.*, 2001)** and the standard deviation (Table-1) was also calculated **(Ram *et al.*, 2008).** Tree ring chronologies were developed **(Meldahl *et al.*, 1999)**.

Table 1: General statistics of tree-ring chronologies

Area	Purna	Waghai	Shoolpa-neshwar	Jambu-ghoda	Ratan-mahal	Bala-ram	Gandhi-nagar	Ahmeda-bad	Gir
Period	1952-2010	1923-2010	1959-2010	1998-2010	1975-2010	1983-2010	1992-2010	1976-2010	1973-2010
Years	58	87	51	12	35	27	18	34	37
No. of cores (trees)	14 (7)	12 (6)	12 (6)	6 (3)	22 (11)	6 (3)	12 (8)	8 (4)	12 (6)
Standard deviation	0.24 (0.19)	0.29 (0.18)	0.20 (0.15)	0.19 (0.14)	0.31 (0.12)	0.36 (0.21)	0.31 (0.15)	0.35 (0.28)	0.23 (0.21)
Correlation with rainfall, R^2	0.04	0.019	0.047	0.270	0.118	0.077	0.139	0.019	0.06
Correlation with temp-erature, R^2	0.05	0.003	0.004	0.24	0.483	0.146	0.075	0.105	0.081

The ring width so observed were then analysed and correlated with the temperature and precipitation data of the particular place to know the impact of climate on the tree growth. Temperature and rainfall data were available from the Indian Meteorological Department. Correlation coefficients were calculated between ring widths of each tree with the ambient temperature and precipitation respectively. Coefficient of correlation was calculated for seasonal and monthly precipitation, minimum and maximum temperature. Monthly minimum temperature and precipitation significantly influence total ring development **(Meldahl *et al.*, 1999).**

Correlation of ring widths with drought events in Gujarat

The tree ring widths of the sample from all the sites were plotted against the year of their formation. The trend in tree ring width size fluctuation was then analysed for all the severe drought years in Gujarat. This analysis was done to study what influence the drought period has on the tree ring formation in various agroclimatic zones of Gujarat.

RESULT AND DISCUSSION

Tree ring analysis of *Tectona grandis*

Teak is a tropical species and found over the entire monsoon belt of south and south-east Asian region. Dendroclimatological studies of teak from India, Myammar, Thailand, Indonesia **(Pant and Borgaonkar, 1983; Bhattacharyya *et al.*, 1992; Murphy and Whetton, 1989; Pumijumnong *et al.*, 1995; Jacoby and D'Arrigo, 1990; D'Arrigo *et al.*, 1994)** suggested its suitability to understand the past vagaries of monsoon. In teak, local climate effect is more prominent than the regional or global signals **(Ram *et al.*, 2008).**

Growth of trees is primarily controlled by the most growth limiting factor; rainfall, in case of teak trees from India. **Priya and Bhatt (1999)** have demonstrated that the cambial activity of teak is influenced by rainfall. Hence, ring-width variations are expected to show a good correlation with rainfall amount. However, widths of all the samples analyzed in the present study do not show any significant relationship with the amount of rainfall except for the samples from Jambughoda and Ratanmahal. The lack of correlation could be attributed to different reasons. The results of the present study show that *Tectona* trees at most sites do not respond to either temperature or rainfall variations. In a few places however, *Tectona* trees respond to temperature and rainfall albeit with a low sensitivity.

The tree ring samples of Purna, Waghai and Shoolpaneshwar show negligible or no correlation with rainfall as well as temperature pattern (Fig- 3-8 respectively). This is because of the fact that they have access to permanent source of ground water for their growth. Another reason is that climate of South Gujarat is moderate, not impacted by temperature extremes and drought conditions and the seasonal rainfall always occurs in adequate amounts ranging fron 1000-1500 mm. Normal or above normal rainfall is not reflected as a significant higher growth. This is mainly because of moisture available at the root zone of the tree **(Ram *et al*., 2008).**

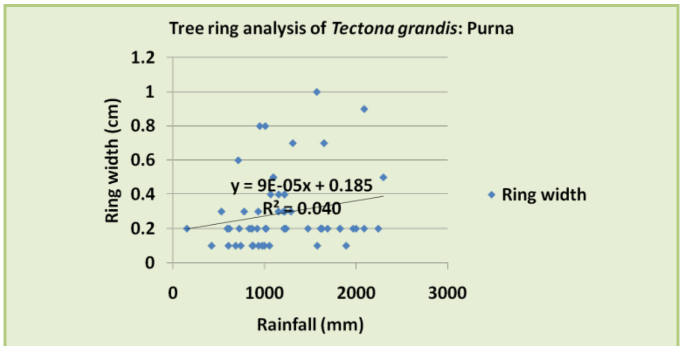

Figure-3: Graph showing correlation between ring width size of Tectona tree and rainfall in Purna, Gujarat

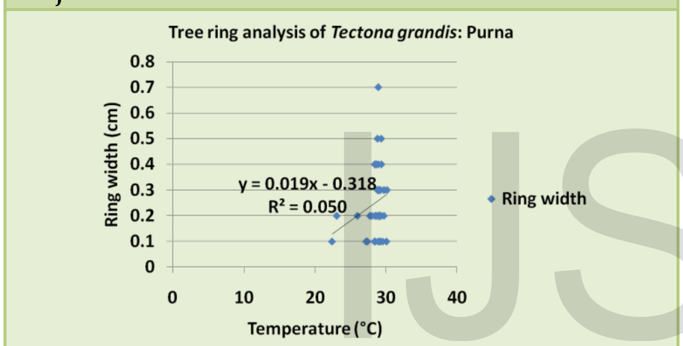

Figure-4: Graph showing correlation between ring width size of Tectona tree and temperature in Purna, Gujarat

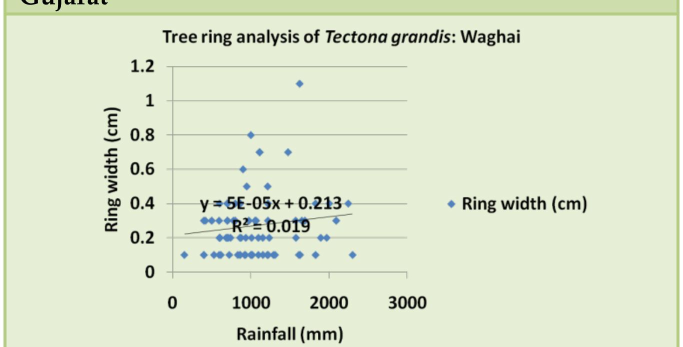

Figure-5: Graph showing correlation between ring width size of Tectona tree and rainfall in Waghai, Gujarat

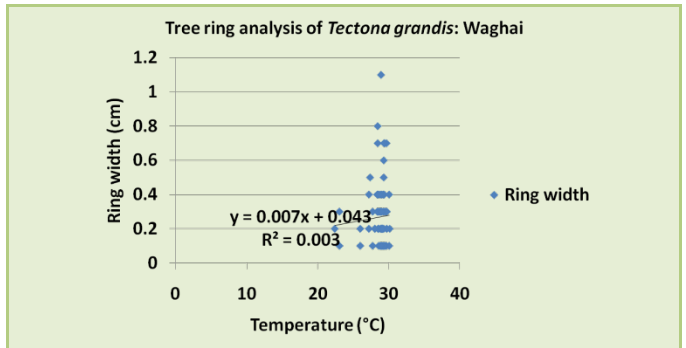

Figure-6: Graph showing correlation between ring width size of Tectona tree and temperature in Waghai, Gujarat

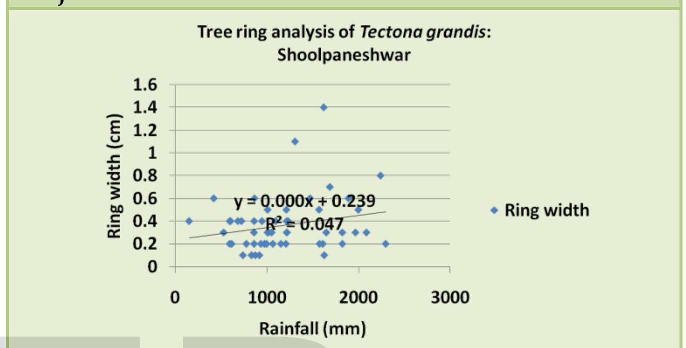

Figure-7: Graph showing correlation between ring width size of Tectona tree and rainfall in Shoolpaneshwar, Gujarat

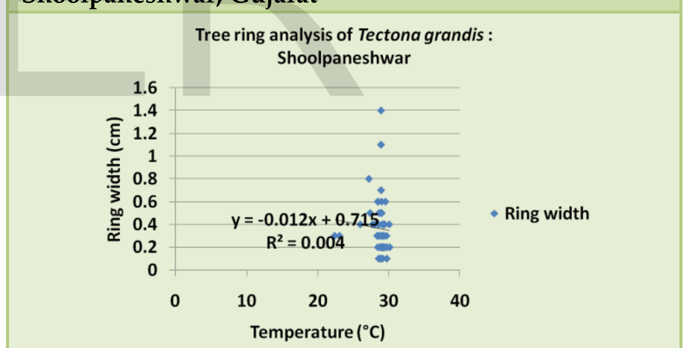

Figure-8: Graph showing correlation between ring width size of Tectona tree and temperature in Shoolpaneshwar, Gujarat

However a few trees did show significant correlation with their ambient temperature and rainfall data. Jambughoda and Ratanmahal show good correlation with ambient temperature (Fig-10 & 12 respectively). The trees from Balaram, Gandhinagar, Ahmedabad and Gir show a less significant relation with ambient temperature (Fig-14, 16, 18 & 20 respectively). Though the temperature is an important parameter in photosynthesis, the correlation analysis indicates the least effect of direct influence of temperature on tree-ring variations. Higher temperature always accelerates evaporation and evapotranspiration which creates a severe moisture stress condition causing the below normal growth (narrow rings) **(Ram *et al.*, 2008).**

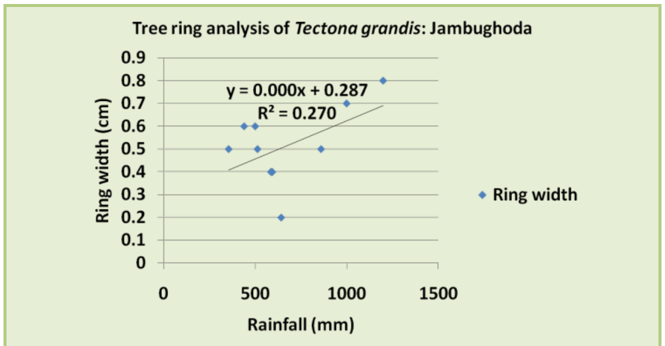

Figure-9: Graph showing correlation between ring width size of Tectona tree and rainfall in Jambughoda, Gujarat

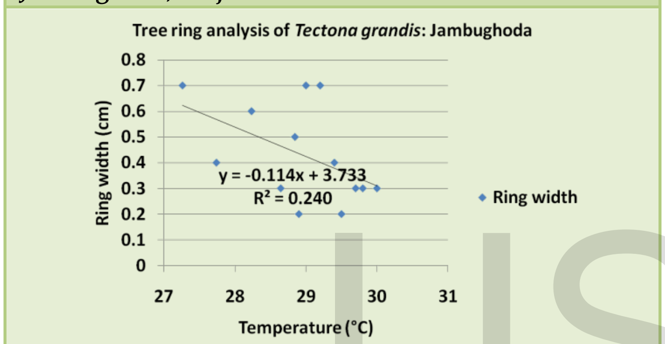

Figure-10: Graph showing correlation between ring width size of Tectona tree and temperature in Jambughoda, Gujarat

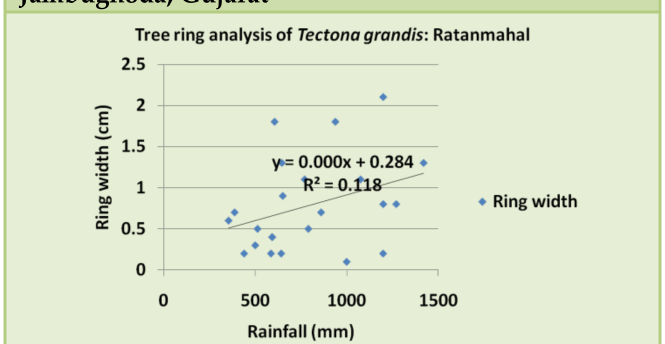

Figure-11: Graph showing correlation between ring width size of Tectona tree and rainfall in Ratanmahal, Gujarat

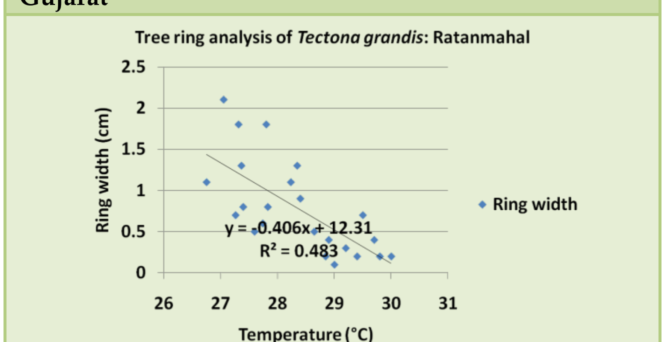

Figure-12: Graph showing correlation between ring width size of Tectona tree and temperature in Ratanmahal, Gujarat

Jambughoda, Ratanmahal and Gandhinagar show good correlation with rainfall (Fig-9, 11 & 15 respectively). **Di´Az et al., (2001)** found that the winter rainfall enhances the tree ring growth in comparison to the summer rains in Pine trees of Baja, Mexico. The trees from Balaram and Gir also were related less significantly to ambient rainfall (Fig-13 & 19 respectively), while, Ahmedabad showed negligible correlation with rainfall pattern (Fig-17). **Borgaonkar *et al.*, (2007)** and **Ram *et al.*, (2008),** based on analysis of teak trees from central and southern India, demonstrated a significant correlation between ring-width and pre-monsoon and post-monsoon climate and suggested role of a moisture index rather than total rainfall as a major factor controlling ring-width variations. This demonstrates that, depending on the locality, rainfall during some months is more important than the other. In this context, it is important to know whether trees are over-irrigated i.e. rainfall is not a growth limiting factor during the periods of higher intensity rainfall. In the first case soils would be filled up to field capacity and excess water would move to the deeper soil layers while the latter implies more surface runoff. This would partly explain low correlation between total rainfall and ring-width variations.

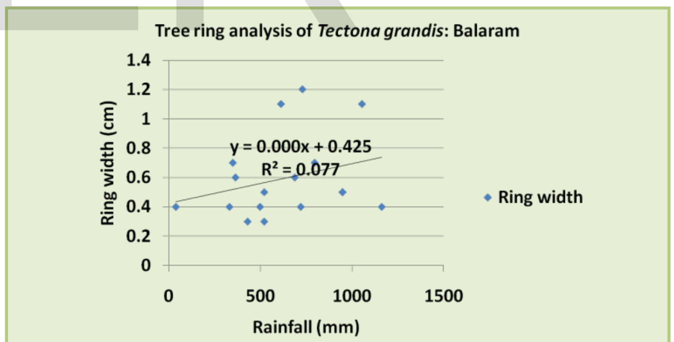

Figure-13: Graph showing correlation between ring width size of Tectona tree and rainfall in Balaram, Gujarat

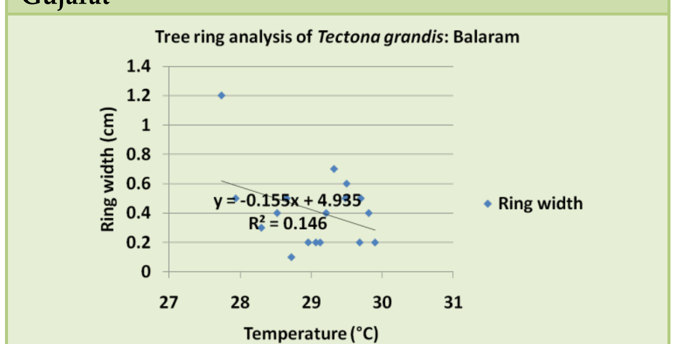

Figure-14: Graph showing correlation between ring

width size of Tectona tree and temperature in Balaram, Gujarat

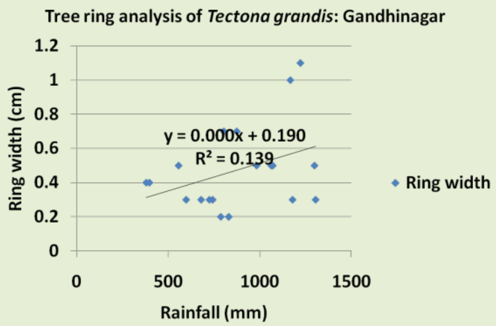

Figure-15: Graph showing correlation between ring width size of Tectona tree and rainfall in Gandhinagar, Gujarat

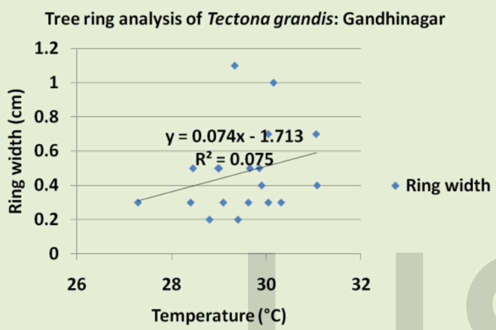

Figure-16: Graph showing correlation between ring width size of Tectona tree and temperature in Gandhinagar, Gujarat

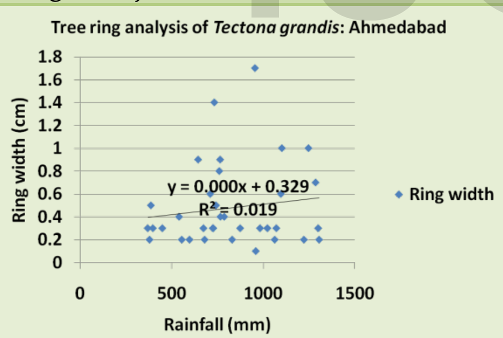

Figure-17: Graph showing correlation between ring width size of Tectona tree and rainfall in Ahmedabad, Gujarat

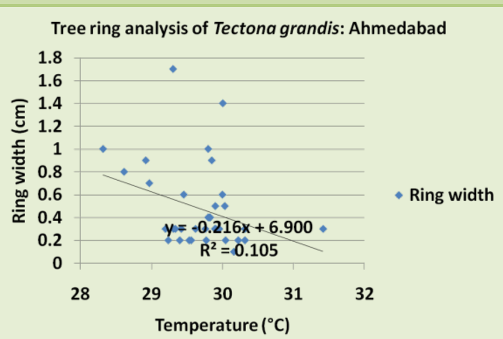

Figure-18: Graph showing correlation between ring width size of Tectona tree and temperature in Ahmedabad, Gujarat

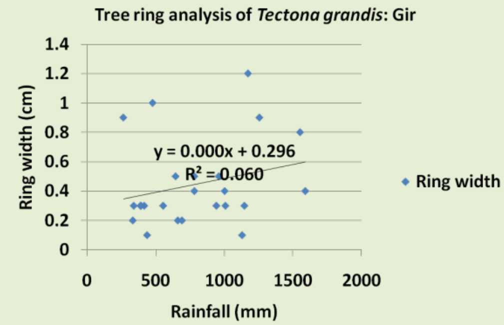

Figure-19: Graph showing correlation between ring width size of Tectona tree and rainfall in Gir, Gujarat

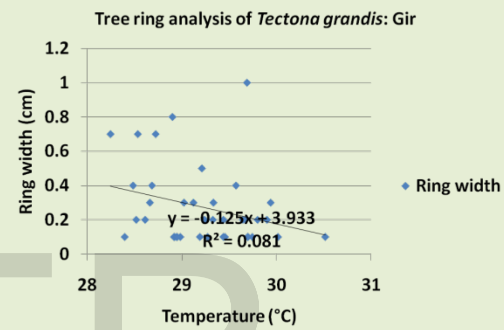

Figure-20: Graph showing correlation between ring width size of Tectona tree and temperature in Gir, Gujarat

In addition to the climatic factors, tree growth, and hence ring-width, is also controlled by parameters such as soil quality, age of tree, competition between trees, gravity stress, crown position of tree. Attack by teak defoliator (*H. puera*) is also reported to reduce the growth of teak **(Sudheendrakumar *et al.*, 1993).**

Correlation of ring widths with drought events in Gujarat

The ring width chronologies so obtained were plotted against the total years of their formation and correlated with the major drought years in Gujarat (Fig-21). Droughts occurred in Gujarat in the years 1956, 1985, 1986, 1987, 1998, 1999, 2000, 2001, 2002, 2008 and 2009 **(Parmar *et al.*, 2005; Attri and Tyagi, 2010)** from which drought during the years 1985, 1987, 1998, 2000, 2002, 2008 and 2009 were most severe. The relation of narrow ring width to the drought years is more pronounced in the rings of Central Gujarat (Ratanmahal and Jambughoda), North Gujarat (Balaram, Ahmedabad and Gandhinagar) and South Saurashtra (Gir) while, the tree rings of South Gujarat (Purna, Waghai and Shoolpaneshwar) do not show any relation with the drought years. **Deepak *et al.*, (2010)** have concluded that teak has been found to have good potential to know rainfall pattern, mostly the drought years. According to **Therrell *et al.*, (2006)** typically drought years are better estimated than extremely wet conditions because moisture deficit is normally the most important limiting factor to tree growth. **Ram *et al.*, (2008)** in his general observations on relationship between the teak ring width variations and climatic parameters revealed that the low growth years (narrow ring) are significantly associated with deficient rainfall (drought condition) in most of the cases. Higher rainfall during any particular year helps in maintaining the normal growth of the tree for the next two-three years even though the rainfall during these years could be less. The reverse process is also true when very less rainfall during any particular year creates moisture stress condition at root zone which may continue in the next one-two years resulting in below normal tree growth in successive years.

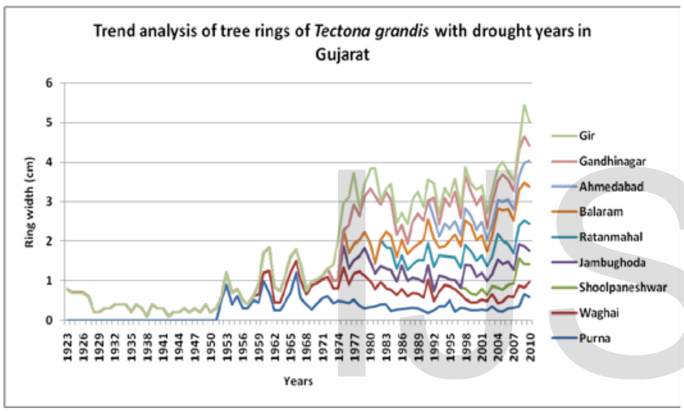

Figure-21: Showing the decreasing trend in the ring width in for particular drought years- 1985, 1987, 1992, 1998, 2000, 2002 and 2008.

CONCLUSION

The results show that *Tectona* trees at most sites do not respond to either temperature or rainfall variations because they have permanent source of ground water for their growth. In a few places (Ratanmahal and Jambughoda) however, trees respond to temperature and rainfall albeit with a low sensitivity. The *Tectona* tree ring width of Gir, Ahmedabad, Gandhinagar, Balaram, Ratanmahal and Jambughoda showed good relation to the drought years in Gujarat. The rings formed in these particular years were very narrow in comparison to other years. While the rings formed in the tree samples of South Gujarat showed no relation to the drought years in Gujarat as these areas are not affected by climate extremes such as drought.

ACKNOWLEDGEMENT

I sincerely thank DST Inspire, India for financial support. I also thank Nisha Patel, Alpesh Ahir, Javed Arambhiya, Alay Mehta and Dhruvi Soni for their sincere support in the field work without whose support my work would not have been a success.

REFERENCES

[1] Attri, S. D. and Tyagi, A. (2010). Climate Profile of India. Pubs. Environment Monitoring and Research Centre, India Meteorological Department, New Delhi, India. Pp: 1-122

[2] Berlage, H. P. (1931). On the relationship between thickness of tree ring of Djati trees and rainfall on Java. *Tectona*, 24: 939–953.

[3] Bhattacharyya, A, Yadav, R. R., Borgaonkar, H. P. and Pant, G. B. (1992). Growth-ring analysis of Indian Tropical trees, Dendroclimatic potential. *Current Science*, 62: 736–741.

[4] Borgaonkar, H. P., Sikder, A. B., Somaru Ram, Rupa Kumar, K. and Pant, G. B. (2007). Dendroclimatological investigations of high altitude Himalayan conifers and tropical teak in India. *Korean Journal of Quaternary Research*, 21: 15–25

[5] Bradley, R. S., Jones, P. D. and Jouzel, J. (1996). Climatic variations and Mechanisms of the last 2000 years. Pubs. Springer, Berlin. Pp: 649

[6] Briffa, K. R., Osborn, T. J. and Schweingruber, F. H. (2004). Large-scale temperature inferences from tree rings: a review. *Global Planetary Change*, 40: 11–26

[7] Buckley, B. M., Palakit, K., Duangsathaporn, K., Sanguantham, P. and Prasomsin, P. (2007). Decadal scale droughts over northwestern Thailand over the past 448 years: links to the tropical Pacific and Indian Ocean sectors. *Climate Dynamics*, 29: 63–71.

[8] Chowdhury, K. A. (1939). The formation of growth rings in Indian trees. Part I. Manager of Publications, New Delhi, India. Pp: 1-39

[9] Cook, E. R. (1987). The decomposition of tree ring series for environmental studies, *Tree-Ring Bulletin.* 47: 37–59.

[10] D'Arrigo, R. D., Jacoby, G. C. and Krusic, P. (1994). Progress in dendroclimatic studies in Indonesia. *Journal of Terrestrial, Atmospheric and Oceanic Sciences*, 5: 349–363.

[11] Deepak, M. S., Sinha, S. K. and Rao, R. V. (2010). Tree-ring analysis of teak (*Tectona grandis* L. f.) from Western Ghats of India as a tool to determine drought years. *Emirates Journal of Food and Agriculture*, 22: 388-397

[12] Di´Az, S. C., Touchan, R., and Swetnam, T. W. (2001). A Tree-Ring Reconstruction of Past Precipitation for Baja California Sur, Mexico. *International Journal of Climatology*, 21: 1007–1019

[13] Esper, J., Cook, E. R. and Schweingruber, F. H. (2002). Low frequency signals in long tree-ring chronologies

and the reconstruction of past temperature variability. *Science* 295: 2250–2253.

[14] Fritts, H. C. (1976). Tree-rings and climate. Academic Press, London. Pp: 567

[15] Jacoby, G. C. and D'Arrigo, R. D. (1990). Teak (*Tectona grandis* L. F.), a tropical species of large-scale dendroclimatic potential. *Dendrochronologia*, 8: 83–98.

[16] Juknys, R., Stravinskiene, V. and Vencloviene, J. (2002). Tree-Ring Analysis for the Assessment of Anthropogenic Changes and Trends. *Environmental Monitoring and Assessment*, 77: 81–97

[17] Managave, S. R., Sheshshayee, M. S., Borgaonkar H. P., and Ramesh, R. (2010). Intra-annual oxygen isotope variations in central Indian teak cellulose: Possibility of improved resolution for past monsoon reconstruction. *Current Science*, 98: 930-937.

[18] Mann, M. E., Bradley, R. S. and Hughes, M. K. (1999). Northern Hemisphere temperature during the last millennium: Influences, uncertainties and limitations. *Geophysical Research Letters*, 26:759–762.

[19] Meldahl, R. S., Pederson, N., Kush, J. S., Varner, J. M. (1999). Dendrochronological Investigations of Climate and competitive effects on Longleaf Pine growth. In: Tree-Ring Analysis-Biological, Methodological and Environmental Aspects. Eds. Wimmer, R., and Vetter, R. E. Pubs. CAB International. Pp: 265-285.

[20] Murphy, J. O. and Whetton, P. H. (1989). A re-analysis of tree ring chronology from Java. *Proceedings of National Academy of Science*, Netherlands. B 92: 241–257.

[21] Pandey, D. N. (2002). Global climate change and carbon management in multifunctional forests. *Current Science*, 83: 593-602

[22] Pant, G. B. and Borgaonkar, H. P. (1983). Growth rings of teak trees and regional climatology (An ecological study of Thane region); In: Environmental Management. Eds. Singh, L. R., Singh, S., Tiwari, R. C. and Srivastava, R. P. Geography Society. Allahabad, India. Pp: 153–158.

[23] Parmar, R.S., Baby Akula, Shekh, A. M. and Jhala, A. J. (2005). Climatic variability over Gujarat State. *Agrometeorology*, 7: 214-219

[24] Priya, P. B. and Bhat, K. M. (1999). Influence of rainfall, irrigation and age on the growth periodicity and wood structure in teak (*Tectona grandis*). *IAWA Journal*, 20: 181–192.

[25] Pumijumnong, N., Eckstein, D. and Sass, U. (1995). Tree-ring research on *Tectona grandis* in Northern Thailand. *IAWA Journal*, 16: 385–392.

[26] Ram, S., Borgaonkar, H. P., and Sikder, A. B. (2008). Tree-ring analysis of teak (*Tectona grandis* L.F.) in central India and its relationship with rainfall and moisture index. *Journal of Earth System Sciences*, 117: 637–645.

[27] Schweingruber, F. H. (1996). Tree Rings and Environment Dendroecology, Swiss Federal Institute for Forest, Snow and Landscape Research: Paul Haupt Publishers. Berne-Stuttgart-Vienna, 609 p.

[28] Shah, S. K., Bhattacharyya, A. and Chaudhary, V. (2007). Reconstruction of June–September precipitation based on tree-ring data of teak (*Tectona grandis* L.) from Hoshangabad, Madhya Pradesh, India. *Dendrochronologia*, 25: 57–64.

[29] Stokes, M. A. and Smiley, T. L. (1968). An Introduction to Tree Ring Dating, University of Chicago Press, Chicago, USA. Pp: 73

[30] Sudheendrakumar, V. V., Nair, K. S. S. and Chacko, K. C. (1993). Phenology and seasonal growth trend of teak at Nilambur (Kerala), India. *Annals of Forest Science*, 1: 42–46.

[31] Therrell, M. D., Stahle, D. W., Ries, L. P., Shugart, H. H. (2006). Tree-ring reconstructed rainfall variability in Zimbabwe. *Climate Dynamics*, 26: 677–685

[32] Yadav, R. R. and Singh, J. (2002).Tree ring analysis of *Taxus baccata* from the western Himalaya India and its dendroclimatic potential. *Tree Ring Research*, 58: 23-29.

[33] Zhu, H. F., Fang, X. Q., Shao, X. M., and Yin. Z. Y. (2009). Tree ring-based February–April temperature reconstruction for Changbai Mountain in Northeast China and its implication for East Asian winter monsoon. *Climate of the Past*, 5: 661–666.